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Bridging soybean yield gaps in Ghana: opportunities and challenges for sustainable smallholder production and livelihood

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Introduction: Soybean, *Glycine max* (L.) Merr., is a globally important legume that supports food security, nutrition, and sustainable agricultural systems. Compared with cereal crops, soybean improves soil fertility through biological nitrogen fixation, induces suicidal *Striga* germination, reduces greenhouse gas emissions, and enhances resource-use efficiency. Despite favorable agroecological conditions, Ghana's soybean production remains well below its potential.

Method and material: This research systematically reviewed published literature on global and subregional soybean production, harvested area, and yield to identify gaps and limitations in Ghana's soybean production systems.

Results: In Sub-Saharan Africa, soybean production is increasing primarily driven by harvested area expansion rather than yield improvement, with yield gap still lagging global averages by 46%. In Ghana, the annual soybean production is estimated at 300, 000 - 350, 000 tons, which represent about 26% of the country's production potential, with a national demand exceeding 600, 000 tons. The national average yield is estimated at 1.85 t ha⁻¹ while the potential yield is estimated at 3.0 tons per hectare. Ghana experiences gaps of 49%, 22%, and 38% in production, area harvested, and yield, respectively. The supply deficit drives import dependence and vulnerability to global price fluctuations. Key constraints identified include climate variability, limited cultivar diversity, low mechanization, suboptimal agronomic practices, weak market integration, and inadequate policy support.

Discussion: Global soybean production has achieved relatively high yields driven by widespread adoption of improved technologies, advanced breeding programs, mechanization, and precision agronomic practices. However, yields in Sub-Saharan Africa and Ghana, remain substantially lower, highlighting persistent yield gap. Addressing this gap requires a multi-pronged strategy. Support for breeding programs for improved, high-yielding and stress-tolerant cultivars, climate-smart agronomic practices, conservation agriculture, and integrated soil fertility management. Supportive policies such as increased access to appropriate mechanization, strengthened agricultural extension and advisory

services, market frameworks that incentivize production and reduce risks for smallholder farmers are required.

Conclusion: Closing Ghana's soybean yield gap is critical given rising population, dietary shifts toward plant-based proteins, and expansion of the feed industry. Addressing yield gap limitations can enhance productivity, reduce import reliance, promote sustainable livelihoods, support economic growth, and contribute to a resilient and sustainable food system.

KEYWORDS

climate-smart agriculture, Ghana, legume crops, soybean production, sustainable food systems, value chains, yield gap

Highlights

- Enhancing food security and reducing dependency on imports.
- Empowering smallholder farmers and improving rural livelihoods.
- Enhancing agribusiness investments through value addition and innovation.
- Boosting organic soybean exports for foreign currency while managing imports.
- Promoting sustainable and environmentally friendly soybean production practices.

1 Introduction

Soybeans, *Glycine max* (L.) Merr., are often referred to as the “king of beans” because of their exceptional versatility, high nutritional value, and wide range of applications (Thrane et al., 2017; Hashemi et al., 2022). The crop is a major source of plant-based protein and oil, making it indispensable in human nutrition, animal feed formulations, and numerous industrial processes (Ferrari et al., 2022). Soybean oil is widely used in various edible products, while the meal constitutes a critical component of livestock and poultry feed. Soybeans also provide raw materials for various industrial products, including biodiesel, pharmaceuticals, and biodegradable materials (Hartman et al., 2011).

Soybean is highly adaptable across diverse agro-ecological zones and ecoregions, thriving on a wide range of soil types and under varied farming systems (Hartman et al., 2011). Brazil, United States, and Argentina are the world's leading soybean producers, driven by technology, improved cultivars and management (Ritchie, 2021). The U.S. soybean industry for example, in 2023 contributed approximately \$124 billion to the U.S. economy, and supported over 500,000 jobs across production, processing, transportation, and export sectors (Vassalli and Murphy-Spooner, 2023). This illustrates the broad economic impact soybean production can create when supported by strong infrastructure, policy frameworks, and market systems. However, developing countries are constrained in soybean production due to climate variability,

resource limitations, and technological advancements resulting in persistent yield gaps (Sedibe et al., 2023).

Stable and sustainable food production is increasingly critical as the world's population is projected to reach over 9 billion by 2050 (UN-FAO, 2009). Approximately three-quarters of total global soybean production is devoted to animal feed for meat and dairy production systems (Ritchie, 2021). While one-fifth is processed into edible oil and various soy-based food products for human consumption, roughly 4% is directed toward industrial applications, including biofuels and other value-added products (Ritchie, 2021).

In Sub-Saharan Africa (SSA), soybean production experiences significant yield gap when compared to global average yield (Ritchie et al., 2023). Bridging the soybean yield gap in sub-Saharan Africa requires a comprehensive approach to enhance productivity while reducing environmental impact and ensuring long-term sustainability. Hence, careful environmental management is required to ensure sustainability and enhanced productivity (Ritchie, 2021).

In Ghana, soybeans were introduced into the then Gold Coast (now Ghana) during the colonial period in 1909 (Mercer-Quarshie and Nsowah, 1975) and are well adapted to the extensive savanna agroecological zones that cover about 63% of Ghana (SRID-MoFA, 2025). Beyond their economic value, soybeans contribute significantly to environmental sustainability by enhancing soil fertility through biological nitrogen fixation (BNF), where atmospheric nitrogen is converted into plant-available forms in the soil for plant use (Islam et al., 2022). Certain soybean cultivars are highly effective as trap crops, inducing the “suicidal germination” of the parasitic weed *Striga hermonthica*, that severely constrain cereal yields in northern Ghana (Scholes and Press, 2008).

Ghana's soybean production remains underdeveloped, with current output between 300,000–350,000 metric tons annually, far below the estimated national potential of about 700,000 metric tons (SRID-MoFA, 2025). However, the national soybean demand is estimated at 600,000 metric tons annually, more than double current production, driven primarily by livestock feed, aquaculture, and food processing (SRID-MoFA, 2025). This persistent supply gap compels Ghana to depend on soybean imports. In 2024, Ghana imported \$37.2M worth of soybean meal, becoming the 85th largest importer of soybean meal that year out of 174 countries in the world.

Although Ghana's soybean industry holds considerable potential to expand and stimulate growth within the agricultural economy (Frimpong, 2024; Taylor and Tuebner, 2024), the region's unimodal rainfall pattern theoretically constrains production (SRID-MoFA, 2025). Consequently, many local processing companies struggle to secure sufficient raw materials to sustain their operations (Frimpong, 2024; Taylor and Tuebner, 2024). Figure 1 illustrates a conceptual framework of sustainable, climate-smart approach to soybean production in northern Ghana where climate variability, soil degradation, and limited institutional support constrain soybean productivity, critical for closing yield gaps.

The framework integrates high-yielding and drought-tolerant cultivars, integrated pest management, improved agronomic practices, soil fertility management, and institutional capacity for research and extension. The interaction among these components enhances productivity, yield stability, and resilience of soybean systems under climate variability to increase soybean supply.

Despite the challenges, stakeholders across the soybean value chain remain optimistic of Ghana's soybean production potential, as a significant future player in the global soybean market (Frimpong, 2024; Taylor and Tuebner, 2024). By expanding local soybean cultivation, the country can reduce import dependency, strengthen domestic industries, enhance food and feed, and tap into the growing global market.

Soybean is a driver of economic growth and transformation for smallholder farmers, particularly women and marginalized groups. The primary objective of this review paper is to examine Ghana's soybean production potential and explore yield gaps, opportunities, constraints, and prospects for sustainable production to

transformation of Smallholder livelihoods. The paper reviewed the health benefits of soybean consumption to human health, examined global soybean production, yield and yield trends, including those of Sub-Saharan Africa and Ghana. It further identified the constraints and challenges facing the country's soybean sector and explored sustainable implementation pathways to enhance soybean production and reduce yield gaps.

2 Systematic review methodology

2.1 Review approach and research framework

This study employed a systematic review approach to synthesize evidence on soybean yield gaps in Ghana, including global production systems and across Sub-Saharan Africa. The review focused on production constraints, opportunities, and strategies for sustainable intensification based on a decade (2014–2023) of Soybean Management with Appropriate Research and Technology (SMART) Farm research conducted at three locations in northern Ghana: Nyankpala (9.40482° N, −0.95272° W; 165 m AMSL), Wa (10.07748° N, −2.50582° W; 301 m AMSL), and Manga (11.01712° N, −0.26173° W; 100 m AMSL). The research was implemented through a collaborative partnership among the Savanna Agricultural Research Institute (SARI), Ghana; Mississippi State University (MSU); and the Soybean Innovation Laboratory (SIL).

The SMART Farm experimental data and literature review methodologies are integrated through evidence-based, data-driven

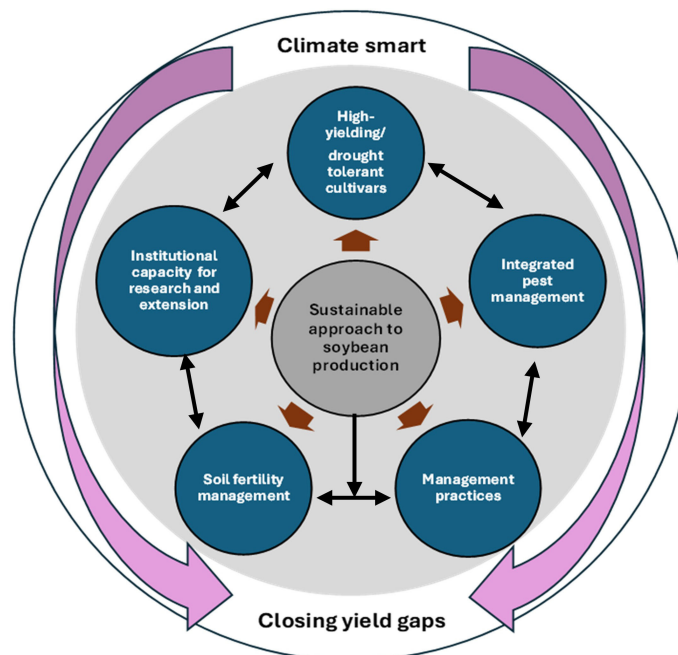


FIGURE 1

Conceptual framework illustrating how climate-smart agriculture (CSA) mitigates interacting biotic (pests and diseases) and abiotic (climate and soil) constraints to reduce the gap between potential and actual soybean yields, improving productivity, yield stability and resource-use efficiency under climate change.

framework, where empirical field data are used to validate, refine, or challenge the established knowledge obtained from literature. These sources collectively establish an analytical framework that integrates real-time ground-truth data with systematic knowledge, enabling predictive modeling for optimized and sustainable agricultural decision-making.

The review was guided by the research question: among smallholder soybean farmers in Ghana, how do improved agronomic and soil fertility management practices, compared with traditional farming practices, influence soybean yield gaps, productivity, and smallholder livelihoods? To address this question, the review synthesized both theoretical frameworks and empirical evidence from global and Sub-Regional soybean production systems to contextualize yield performance and identify relevant strategies for improving productivity in Ghana.

2.2 Literature search strategy

The study synthesized evidence from peer-reviewed journal articles, extension publications, and applied research reports on global soybean production, with particular emphasis on Sub-Saharan Africa and Ghana. Literature searches were conducted using major academic databases, including Scopus, Crossref, Web of Science, Google Scholar, and AGRICOLA.

Search strings combined terms related to soybean (or soybean, Glycine max), yield gaps (or productivity, crop yield), soil fertility management (or phosphorus fertilization, rhizobial inoculation, improved variety), climate-smart agriculture (or sustainable intensification), smallholder farmers (or small-scale farmers), soybean consumption (or human health benefits, nutrition benefits), and geographic scope (Ghana, Sub-Saharan Africa, or global production).

This approach ensured a comprehensive capture of both global and region-specific studies relevant to soybean yield gaps, agronomic practices, and the socio-economic impacts on smallholder livelihoods.

2.3 Inclusion and exclusion criteria

Priority was given to peer-reviewed publications, technical reports, and applied research studies, with particular emphasis on global, sub-regional, and Ghana's soybean production. Smallholder soybean farming, yield trends and gaps, productivity, soil fertility, or agronomic interventions were included in the search criteria. Studies that were not related to soybean yield gaps or soybean production were excluded and limited to peer-reviewed articles published in English only. The review focused on published literature between 2000 and 2026 to capture recent developments in soybean production and productivity.

Studies that met the inclusion criteria were synthesized and systematically reviewed around the PICO framework (Population, Intervention, Comparison, and Outcome), a method widely used to structure evidence-based research. The population in this review consisted of soybean production systems; the intervention included improved agronomic practices, soil fertility management strategies, and improved soybean varieties; the comparison

involved global, sub-regional, and national soybean production; and the outcomes focused on soybean yield levels, yield gaps, productivity improvements, and implications for smallholder livelihoods. The review also integrated theoretical perspectives and empirical findings from global and Sub-Saharan African soybean production systems to provide broader contextual insights relevant to Ghana.

2.4 Study selection and screening

Only peer-reviewed articles, reports, and studies addressing soybean production, yield trends, and yield gaps in global, sub-regional, and particularly Sub-Saharan African contexts were retained for analysis. Articles were assessed for relevance, methodological quality, and reporting of outcomes across global soybean production systems. The selected studies were analyzed to identify patterns, constraints, opportunities, and trends in soybean productivity. Emphasis was placed on understanding yield trends, the magnitude and drivers of yield gaps, and the potential pathways for improving soybean productivity and enhancing the sustainability of smallholder production systems.

2.5 Data extraction and synthesis

The analysis prioritized peer-reviewed literature and applied research, with production parameters evaluated in terms of technical efficiency, economic viability, and environmental sustainability. Data from the selected studies were systematically extracted using a structured data extraction form to ensure consistency and reduce bias. Information collected included authors, publication year, study location, study design, characteristics of the study population, soybean production systems, agronomic and soil fertility management practices, comparison practices, and outcomes related to soybean yield, yield gaps, and productivity. Additional details on production constraints, opportunities for yield improvement, and implications for smallholder livelihoods were also recorded.

The extracted data were organized in tabular form to facilitate comparison across studies. A narrative synthesis approach was used to integrate the findings due to variations in study designs, agroecological conditions, and measurement methods. Studies were grouped into key thematic areas such as yield trends, soil fertility management, improved soybean varieties, agronomic practices, and socio-economic constraints. This thematic analysis enabled the identification of major drivers of soybean yield gaps, potential opportunities for sustainable intensification, and the development of an implementation roadmap for a national sustainable soybean production to improve smallholder livelihoods.

The soybean yield gap was calculated using the standard formula:

$$\text{Yield gap (\%)} = \frac{\text{Potential yield} - \text{Actual yield}}{\text{Potential yield}} \times 100$$

All intellectual contributions, interpretations, and synthesis of the literature presented in this review are solely those of the author(s).

3 Results

3.1 Soybean consumption and human health benefits

Soybeans are considered as a global “health crop” valued for its nutritional value, versatility, and role in combating malnutrition and chronic diseases. Traditionally consumed as whole beans in Asia, soybeans are processed into diverse food products in other regions, including plant-based meat alternatives for their plant protein, antioxidants, and phytonutrients which provide numerous health benefits (Rizzo and Baroni, 2018).

A 172 g cup of boiled soybeans provides about 31 g of protein (USDA-ARS, 2019); however, on a dry weight basis, soybeans contain 36–56% protein (Grieshop and Fahey, 2001; Grieshop et al., 2003). The protein is mainly globulins (glycinin and beta-conglycinin) and albumins, which make up roughly 80% of total protein, though it may be slightly lower in quality compared with some animal proteins (Devries and Phillips, 2015; Liu, 2016; Berrazaga et al., 2019).

Regular soybean consumption is associated with multiple health benefits, including improved heart health (Berrazaga et al., 2019). Soy protein intake has been linked to modest reductions in cholesterol levels (Sirtori and Lovati, 2001), while its high fiber content supports gut health and may lower colon cancer risk (Dinoto et al., 2006; Zimmerman et al., 2012). Additionally, soybeans provide essential vitamins and minerals such as molybdenum, vitamin K1, folate, copper, manganese, phosphorus, and thiamine (Hattori et al., 2004; Shea and Booth, 2008; Fekete et al., 2012). Soy contains bioactive compounds that contribute to its health-promoting properties (Messina et al., 2022). Isoflavones, believed to have estrogen-like activity, play a central role in many of

soy's benefits, including lower risk of cancers, and improved bone health and decreased risk of osteoporosis (Howes et al., 2006; Taku et al., 2011; Wang et al., 2024).

Most global soy production is used for livestock feed rather than human consumption (Ritchie et al., 2023) and increasing soy in human diets could significantly enhance global nutrition. However, evidence suggests potential adverse effects of soy consumption for some individuals (Fruzza et al., 2012). These may include suppression of thyroid function in susceptible individuals (Taku et al., 2011), digestibility and allergy (Otun et al., 2019), and other anti-nutritional effects when not adequately heat-treated (Mishra et al., 2024).

3.2 Global and sub-regional soybean production and yield trends (2013 – 2023)

3.2.1 Global production and yield trends

Soybean production is determined by both the area harvested and yield per unit hectare. Global soybean production is outpacing many major staple crops, including wheat, rice, and to some extent corn (Smith and Goodwin, 2024). Table 1 illustrates that global soybean output increased by approximately 34%, from 277.66 million tons to 371.17 million tons between 2013 and 2023, respectively. This was largely driven by growing demand for animal feed and soybean oil, particularly in developing countries where rising incomes and increased livestock consumption is taking the center stage (USDA-FAS, 2025; UN-FAO, 2025; Ritchie et al., 2023).

Within the period under review, Russia and Africa recorded the highest relative percentage increase in production (ΔRP) with +334% and +234%, respectively; largely due to increase in cultivated area of +192 and +162 for Russia and Africa, respectively

TABLE 1 Comparative trends in soybean production, harvested area, and yield among major global producing countries, including Africa and Ghana (2013–2023).

Location	Production (million t)		ΔRP^a (%)	Harvest area (million ha)		ΔRHA^b (%)	Average yield (t ha ⁻¹)		ΔRY^c (%)	ΔRGC^d (%)
	2013	2023		2013	2023		2013	2023		
1. Brazil	81.72	152.14	+86.17	27.91	44.45	+59.26	2.93	3.42	+16.72	+40.99
2. U.S.A.	91.39	113.34	+24.02	30.86	33.35	+8.07	2.96	3.40	+14.86	+30.54
3. Argentina	49.31	25.04	-49.22	19.47	14.36	-26.25	2.54	1.74	-31.50	+6.75
4. China	11.95	19.49	+63.10	6.79	9.98	+46.98	1.76	1.95	+10.80	+5.25
5. India	11.86	14.98	+26.31	11.72	13.08	+11.60	1.01	1.15	+13.86	+4.04
6. Paraguay	9.09	10.20	+12.21	3.08	3.61	+17.21	2.95	2.83	+4.07	+2.75
7. Canada	5.36	6.98	+30.22	1.87	2.26	+20.86	2.87	3.09	+7.67	+1.88
8. Russia	1.52	6.60	+334.21	1.20	3.50	+191.67	1.26	1.89	+50.00	+1.78
9. Ukraine	2.77	4.74	+71.12	1.35	1.83	+35.56	2.05	2.59	+26.34	+1.28
10. Bolivia	2.83	3.67	+29.68	1.22	1.82	+49.18	2.31	2.01	+12.99	+0.99
11. Africa	2.20	7.34	+233.64	1.92	5.03	+161.98	1.15	1.46	+26.96	+1.98
12. Ghana	0.14	0.26	+85.71	0.085	0.14	+64.71	1.64	1.86	+13.41	+0.07
World	277.66	371.17	+33.68	111.10	136.90	+23.22	2.50	2.71	+8.40	

^aRelative change in production; ^brelative change in harvested area; ^crelative change in yield; and ^drelative global contribution (%) in 2023.

Data Source: Food and Agriculture Organization of the United Nations (2025) – with major processing by Our World in Data. <https://ourworldindata.org/grapher/soybean-production?tab=line>.

(Table 1). Significant gains were also observed in Brazil (+86%), China (+63%), Ukraine (+71%), and Ghana (+86%). In contrast, Argentina's production declined by -49% due to severe drought conditions in 2023 (Garcia, 2023). The increases in soybean production largely reflect the expansion of harvested areas, alongside improvements in crop yields, driven by more efficient cultivation practices. These trends highlight the growing global economic and nutritional significance of soybeans.

Although growth in soybean production has been driven primarily by expansion in harvested area and improvements in yield, external factors such as trade dynamics, weather variability, and global demand fluctuations can significantly disrupt output (USDA-FAS, 2025). In 2023, Argentina experienced a severe drought that led to a 49% decline in soybean production, accompanied by a 26% reduction in harvested area and a 32% drop in yield. As a result, Argentina accounted for only about 6% of global soybean output that year (Table 1).

Brazil is currently the global leader in soybean production, accounting for approximately 41% of total world output, followed by the United States (31%) and Argentina (7%). Other significant contributors include China (5%), India (4%), and Paraguay (3%), while Canada, Russia, Ukraine, and Bolivia collectively account for about 6% of global production. In contrast, Africa, including Ghana contributed only 2% to global soybean output, despite experiencing remarkable growth in recent years.

Sub-Saharan Africa's soybean production within the reference periods expanded by +234%, driven primarily by a +162% increase in harvested area and a +27% improvement in yields. Ghana similarly recorded a substantial production increase of 85%, largely attributable to a +65% expansion in cultivated area.

Brazil, the United States, and Canada recorded relatively high average soybean yields of 3.40, 3.42, and 3.09 t/ha, respectively, reflecting the adoption of improved technologies, advanced breeding programs, mechanization, and precision agronomic practices. Turkey, though not listed among the top global producers, reportedly achieved the highest average soybean yield worldwide at 4.21 t/ha, despite a modest total production of 137,500 tons (Ritchie et al., 2023; UN-FAO, 2025).

3.2.2 Sub-regional soybean production and yield trends

Sub-Saharan Africa (SSA) remains a relatively minor contributor to global soybean production. However, there is significant potential for future expansion due to abundant arable land, rising domestic and international demand, and technology improvement to close existing yield gaps (Ongoma et al., 2025). Expanding continental soybean production is critical to enhance sub-regional food security, soil fertility improvement through nitrogen fixation, increase farmers' incomes, and boost national economies. In comparison, Ghana's average yield in 2023 was 1.86 t/ha, which is significantly above Africa's continental average of 1.46 t/ha and higher than yields recorded in both Argentina and India (Table 1). Nonetheless, Ghana's soybean yield increased modestly at +13% (Table 1), suggesting that recent production gains have been driven

mainly through expansion in harvested area rather than substantial yield improvements.

Although SSA is steadily increasing its soybean production, this growth is primarily driven by the expansion of harvested areas rather than improvements in productivity, with yield gains still lagging behind global averages (Table 2).

Soybean production across SSA increased by (+234) mainly through area expansion (+162), driven by agricultural and economic development, but with modest yield gains (+27%) between 2013 and 2023 (Table 2). This increase in soybean development and growth is fueled by rising domestic demand for soy-based foods, livestock and aquaculture feed, industrial uses, and export opportunities (Ritchie et al., 2023; UN-FAO, 2025).

The top three soybean-producing countries in SSA are South Africa, Nigeria, and Zambia with continental output contributions of +38%, +18% and +10%, respectively in 2023 (Table 2). Benin, Malawi, Togo, and Ghana each contributed to continental production with +7%, +5%, +4%, and +4%, respectively; while Ethiopia, Uganda, Burkina Faso, Cameroon, and Zimbabwe collectively account for 9% of SSA's production.

Togo illustrates the region's potential for rapid soybean growth and development, achieving a 21-fold increase in soybean production, driven by an 11-fold expansion in harvested area and an 85% yield improvement (Table 2). This success was fueled through the Enhanced Integrated Framework (EIF) project. This project promoted organic soybean production, trade integration, women's empowerment, and value chain development (Arangüena et al., 2024). This strategically boosted Togo's organic soybean exports to the EU from under USD 700,000 in 2015 to nearly USD 60 million in 2023 (Arangüena et al., 2024). This is a demonstration that soybean is not just another crop, but a proven catalyst for agricultural modernization and economic development when treated as a strategic national priority.

Although continental average yield remains low at 1.46 t/ha, Ethiopia and South Africa achieved the highest average yields with 2.44 t/ha and 2.41 t/ha, respectively (Table 2). Uganda achieved the lowest average yield of 0.71 t/ha, highlighting significant regional yield gap disparities of up to 39% and a global gap of 46% compared to an average global yield of 2.71 t/ha (Ritchie et al., 2023; UN-FAO, 2025).

While yield gaps remain high, sustainable production practices, such as adoption of high-yielding cultivars, proper fertilization, and effective pest and disease management have been adopted (Brown et al., 2015; Ntiamoah et al., 2022; Mirzabaev et al., 2023; Omondi et al., 2024). This is to enhance productivity while minimizing environmental impacts, including deforestation and water pollution. Although Africa's share of global soybean production is currently low, the region is emerging as a major consumer and exporter of organic soybeans to the US and EU (Argus, 2023; Organic and Non-GMO Insights, 2023). Countries including Togo, Ethiopia, Ghana, Uganda, and Nigeria demonstrate SSA's potential to become a leading source of certified organic soybeans, offering significant economic, nutritional, and developmental benefits. Africa's young and growing population, rapid urbanization, and rising incomes are creating significant demand for high-protein

TABLE 2 Comparative trends in soybean production, harvested area and yield among major producing countries in sub-Saharan Africa (2013–2023).

Location	Production (1000 t)		^a ΔRP (%)	Harvest Area (1000 ha)		^b ΔRHA (%)	Average Yield (t ha ⁻¹)		^c ΔRAY %	^d RCC %
	2013	2023		2013	2023		2013	2023		
1. South Africa	784	2, 770	+253	517	1, 150	+122	1.52	2.41	+59	+38
2. Nigeria	518	1, 350	+161	680	1, 200	+76	0.76	1.13	+49	+18
3. Zambia	261	760	+191	121	604	+399	2.16	1.26	-41	+10
4. Benin	75	521	+595	84	519	+518	0.89	1.00	+12	+7
5. Malawi	112	350	+213	114	255	+124	0.98	1.37	+40	+5
6. Togo	13	273	+2, 000	24	273	+1, 038	0.54	1.00	+85	+4
7. Ghana	139	260	+87	85	140	+65	1.64	1.86	+13	+4
8. Ethiopia	61	220	+261	31	90	+190	1.97	2.44	+22	+3
9. Uganda	23	150	+552	46	210	+357	0.50	0.71	+42	+2
10. Burkina Faso	22	129	+486	16	123	+669	1.37	1.05	-22	+2
11. Cameroon	14	109	+679	11	62	+464	1.27	1.75	+33	+1
12. Zimbabwe	67	69	+3	51	38	-25	1.31	1.82	+40	+1
Africa Total	2, 200	7, 340	+234	1, 920	5, 030	+162	1.15	1.46	+27	–

^aRelative change in production; ^brelative change in harvested area; ^crelative change in yield; ^drelative continental contribution in 2023.

Data Source: Food and Agriculture Organization of the United Nations (2025) – with major processing by Our World in Data. <https://ourworldindata.org/grapher/soybean-production?tab=line>.

foods and livestock feed, offering a balance between offering a balance between nutritional needs, market expansion, and domestic agricultural production.

3.3 Ghana's soybean sector: production, smallholders, and socioeconomic impact

Smallholder farmers are central to Ghana's soybean sector and global food security. Globally, approximately 570 million farms produce one-third of the world's food (Lowder et al., 2021), while women in sub-Saharan Africa manage an estimated 33 million smallholder operations (The Conversation, 2025). In Ghana, smallholders constitute over 70% of the agricultural workforce, cultivating an average of 2.0 ha under limited access to inputs, finance, and mechanization (Alidu et al., 2022; UN-FAO, 2025). Supporting smallholder soybean production offers a strategic opportunity for agricultural transformation, echoing the historical impact of cocoa (Ndikumana and Adjei-Mantey, 2025). Transferable frameworks, such as Togo's EIF project, highlight that coordinated investments in input delivery, value-chain integration, market access, and farmer organization can enhance production and livelihoods (Arangüena et al., 2024).

3.3.1 Historical and ecological perspective

Soybeans were introduced to northern Ghana in the 19th century to supplement staple crops, generate export income, and improve soil fertility (Mercer-Quarshie and Nsowah, 1975). Today, cultivation is concentrated in savanna and transitional zones, covering ~62% of the country (Figure 2; Tappan et al., 2017).

Production is heavily clustered in the interior savanna (ESS, CSS, WSS, CGS, and OGS) and in the Northern (39%), Upper West

(27%), Northeast (12%), Savanna (12%), and Upper East (10%) regions of northern Ghana (SRID-MoFA, 2025; USDA-FAS, 2025). This reflects the agroecological suitability and integration into cereal-based smallholder systems in northern Ghana. The ten top districts with highest soybean yields are Mion, West Gonja, Tolon, North Gonja, Bunpurugu/Nakpanduri, Savelugu, Sawla/Tuna/Kalba, Gushiegu, Tamale Metropolis, and Krachi Nchumuru (Table 3). Farms are typically <2 ha, with a national estimated average yield of 1.85 t ha⁻¹ (SRID-MoFA, 2025). However, the typical smallholder yield is less than 1.0 t ha⁻¹ which highlights both the constraints and potential for targeted interventions.

3.3.2 Ghana's soybean industry and economic contributions

Ghana's soybean industry contributes to animal feed, especially for poultry and aquaculture, as well as vegetable oils, paints, and soap, while supporting smallholder income and nutrition (Akuriba and Tangoyire, 2020; Frimpong, 2024). Population growth, rural-urban migration, and an expanding middle class are driving increasing domestic demand for protein-rich foods (Jia et al., 2025). Meeting this demand can reduce costly soybean meal imports and strengthen agro-processing industries, positioning soybean as a key driver of economic growth. The sector is increasingly dynamic, fueled by innovation and technological development (Frimpong, 2024).

3.3.3 Smallholder livelihoods and food security

Soybean is Ghana's third most consumed legume, after peanuts and cowpeas, with per capita intake of 7% (SRID-MoFA, 2025). The domestic market is projected to grow at 9.82% annually by 2027, in

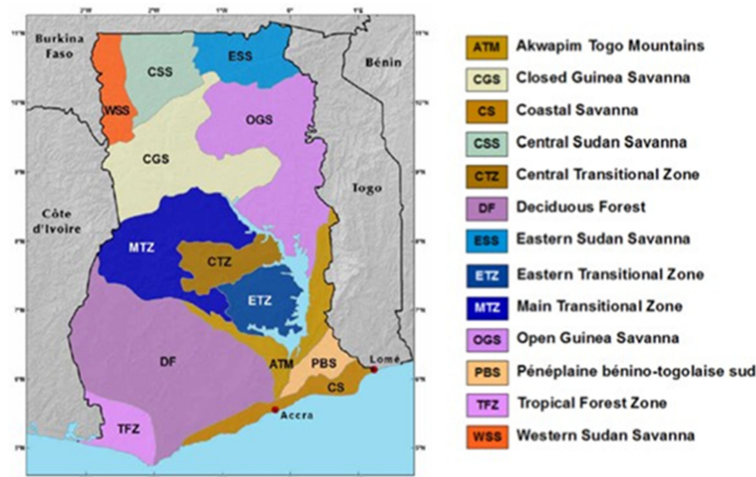


FIGURE 2

Spatial distribution of Ghana's major ecoregions and implications for soybean production. Source: Tappan et al., 2016. Landscapes of West Africa: A Window on a Changing World. USGS Publications Warehouse, pp. 100–117. <https://doi.org/10.5066/F7N014QZ>.

line with trends in South Africa, Ethiopia, Algeria, and Nigeria (Dutta, 2022). Organic soybean exports from SSA have expanded to the US, Turkey, India, Lebanon, and the EU (Argus, 2023; Frimpong, 2024), positioning Ghana as a major regional player alongside Togo, Ethiopia, Nigeria, and Uganda (Argus, 2023).

Smallholder production enhances household income and nutrition, particularly in northern Ghana where farms average 2 ha (SRID-MoFA, 2025). Nucleus-outgrower schemes, where well-resourced farmers provide inputs, training, and market access in exchange for a share of output, facilitate technology adoption, market integration, and production efficiency, though outcomes vary with scheme design and context (Akuriba and Tangonyire, 2020).

3.3.4 Sustainable soybean production

As a nitrogen-fixing legume, soybean improves soil fertility and supports subsequent cereal crops such as maize (*Zea mays* L.), millet (*Pennisetum* spp.), and sorghum (*Sorghum bicolor*). This reduces reliance on inorganic fertilizers, enhances crop rotation benefits, and promotes sustainable smallholder cropping systems.

3.3.5 Production, area harvested, and yield trends in Ghana (2008–2024)

Ghana's soybean sector experienced substantial growth in production, harvested area, and marginal yield improvements

TABLE 3 Three-year (2021 – 2023) soybean yield among major producing districts in Ghana compared with the national average and potential yields.

Region	District	Soybean yield (mt/ha) by year			3-year yield average	3-year yield ranking	National and potential average yields (mt/ha)	
		2021	2022	2023			National average	1.85
							Yield potential	3
							% Yield average over national average	% Yield average relative to potential
Northern	Mion	2.50	2.50	2.50	2.50	1	135.46	83.32
Savanna	West Gonja	2.13	2.47	2.85	2.48	2	134.66	82.83
Northern	Tolon	2.20	2.20	3.00	2.47	3	133.66	82.21
Savanna	North Gonja	2.00	2.37	2.84	2.40	4	130.26	80.13
Northeast	Bunkurugu/ Nakpanduri	1.67	2.21	2.99	2.29	5	124.12	76.35
Northern	Savelegu	2.00	2.20	2.60	2.27	6	122.82	75.55
Savanna	Sawla/Tuna/ Kalba	1.50	2.37	2.75	2.21	7	119.61	73.57
Northern	Gushisgu	2.00	2.10	2.47	2.19	8	118.67	72.99
Northern	Tamale Metro	2.00	2.00	2.20	2.07	9	111.98	68.88
Oti	Krachi Nchumuru	1.91	2.34	1.90	2.05	10	111.06	68.31

Data Credit: SRID-MoFA (2025).

between 2008 and 2024 (Figure 3). In 2008, Ghana produced 75,000 mt of soybeans on 47,266 ha, with yield average of 1.59 mt ha^{-1} (Figure 3). By 2024, production increased by 141% at 270,000 mt with harvested area increase of 122.29% at 148,000 ha, and an average yield increase of 7.45% at 1.86 t ha^{-1} . The trend indicated an increase in production and harvested area from 2008 to 2011 but declined to 2016 with a sustained increase. The significant increase between 2008 and 2011 was driven by rising demand for poultry feed, the expansion of local processing industries, and targeted government and NGO initiatives (Adjei-Nsiah, 2019). The average yield was steady from 2008 to 2012 but peaked in 2013 and sharply dropped to 2014 with fluctuating increase to 1.86 t ha^{-1} in 2024. This reflects roughly 3.8–4.0% annual growth in production over 16 years.

Based on the annual growth rate of approximately 3–4% observed over the 16-year period from 2008 to 2024, a simple trend projection suggests that Ghana could produce approximately 700,000–900,000 metric tons of soybean by 2050. This projection assumes a harvested area of about 280,000–350,000 hectares and an average yield of 2.3–2.8 tons per hectare under improved agronomic management practices.

Despite this progress, Ghana's national production potential is estimated at 700,000 metric tons from a harvested area of 250,000 ha, with potential yield projected at 3.0 t ha^{-1} (UN-FAO, 2023; SRID-MoFA, 2025). However, current production reveals gaps of 49%, 22%, and 38% in production, area harvested, and yield, respectively. Closing these gaps through improved inputs, mechanization, farmer training, and value-chain development could generate employment, enhance regional development, and drive inclusive agricultural growth (Dutta, 2022; Frimpong, 2024).

3.3.6 Progress in soybean genetic improvement

Soybean genetic improvement in Ghana is overseen by the National Variety Release and Registration Committee (NVRRC) and has produced cultivars with targeted traits (Table 4).

Varieties are classified into three maturity groups (MGs) based on physiological maturity: early (90–100 days), medium (105–120 days), and late (≥ 120 days), with variation due to planting date and agro-ecology (Table 4).

Yield gains arise from genetic enhancement and agronomic management, although results are influenced by environmental conditions and genotype $\times$ environment interactions (GEI) (NVRRC, 2019). Since 1985, breeding programs have prioritized seed yield, disease and drought resistance, pod shattering reduction, and adaptation to local agro-ecologies (NVRRC, 2019).

However, low pod clearance remains a challenge, as pods set near the ground increase harvest losses under mechanized systems. Although high-clearance cultivars are increasingly preferred, environmental conditions have been cited to influence the height of the first pod through early growth-stage stresses and management practices.

4 Discussion

4.1 Constraints and challenges to sustainable soybean production in Ghana

Despite the growing significance of soybeans for rural livelihoods, nutrition, and agro-industrial development, Ghana's soybean sector continues to face substantial and persistent yield gaps. Smallholder farmers achieve average yields of only 0.8–1.5 t ha^{-1} , substantially below the potential of 3.0 t ha^{-1} attainable under improved management practices (UN-FAO, 2023; SRID-MoFA, 2025). These yield gaps arise from the combined effects of abiotic stresses, biotic constraints, and socioeconomic limitations, highlighting the multifaceted nature of production challenges within Ghana's soybean systems. Collectively, these constraints restrict productivity, reduce profitability, and hinder the integration of smallholders into formal soybean value chains.

4.1.1 Abiotic constraints

A Decision Support System for Agrotechnology Transfer (DSSAT) crop model across diverse agroecological regions in India quantified potential yields under rainfall and irrigated conditions. The results showed approximately

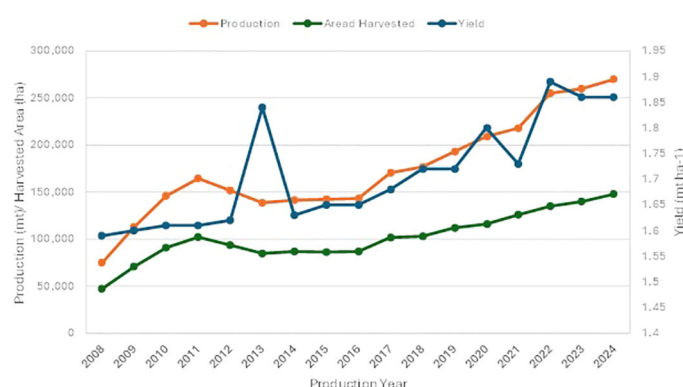


FIGURE 3

Sixteen-year trend in soybean production (metric tons), area harvested (hectares), and average yield (tons per hectare) from 2008 to 2024 in Ghana. Data Source: FAO – United Nations (2025) – with major processing by Our World in Data (2025). <https://archive.ourworldindata.org/20250718-111234/grapher/soybean-production.html?tab=line&country=~GHA&mapSelect=~GHA>.

TABLE 4 Characteristics of commonly cultivated commercial soybean cultivars with traits and descriptions in Ghana.

Cultivar	Breeder institution	Year released	Yield (t ha ⁻¹)	Growth period (d)	Maturity group	1000-seed weight (g)	Traits	Target locations
Salintuya I	CSIR-SARI/IITA	1985	2.2	120	Medium	120	Tolerance to CLS ^a and BP ^b Trap-crop for <i>Striga</i> .	GS ^c , SS ^d , TZ ^e
Salintuya II	CSIR-SARI/IITA	1985	3.2	130	Late	152	Tolerant of soybean pests.	GS, SS, TZ
Anidaso	Landrace CSIR-CRI	1992	2.8	115	Medium	104	Moderate pod shattering.	GS, SS, TZ, CS ^f
Bengbie	Landrace/CSIR-CRI	1992	2.8	110	Medium	100	Moderate pod shattering.	GS, SS, TZ, CS
Jenguma	CSIR-SARI/IITA	2003	2.8	125	Medium	130	Pod shattering (3%). Trap-crop for <i>Striga</i> .	GS, SS, TZ, FZ ^g
Quarshie	CSIR-SARI IITA	2003	2.4	115	Medium	120	Pod shattering (30%). Good <i>Striga</i> trap crop.	GS, SS, TZ
Nangbaar	Landrace/CSIR-CRI	2005	2.1	115	Medium	120	Shattering resistant (5%).	GS, SS, TZ, CS
Ahoto	Landrace/CSIR-CRI	2005	2.4	115	Medium	120	Moderate pod shattering.	GS, SS, TZ, CS
Afayak	CSIR-SARI/IITA	2012	2.4	115	Medium	130	Trap-crop for <i>Striga</i> . Pod shattering (up to 5%).	GS, SS, TZ, CS
Songda	CSIR-SARI/IITA	2012	2.2	115	Medium	118	Excellent <i>Striga</i> trap crop. Pod shattering (50%).	GS, SS, TZ
Suong-Pungun	CSIR-SARI/IITA	2012	2.0	105	Early	140	Pod resistant (up to 3%).	GS, SS, TZ
Gyidie	CSIR-SARI/IITA	2016	3.2	90	Early	145	Rust-tolerant. Promiscuous nodulation.	GS, TZ, CS, FZ
Lalara	CSIR-SARI/IITA	2016	3.2	115	Medium	140	Rust-tolerant. Promiscuous nodulation.	GS, TZ, FZ, CS
Favour	CSIR-SARI/IITA	2019	3.5	130	Late	120	Pod shattering (5%). High nodulation.	GS, SS, TZ, CS
Toondana	CSIR-SARI/IITA	2019	3.5	115	Medium	140	Rust-tolerant. Promiscuous nodulation.	FZ, TZ, CS
Aningye	CSIR-SARI/IITA	2019	3.4	110	Medium	125	Rust-tolerant. Promiscuous nodulation.	TZ, FZ, CS

Source: National Variety Release and Registration Committee (NVRRC), 2019.

^aCercospora leaf blight; ^bBacterial pustule; ^cGuinea savanna; ^dSudan savanna; ^eTransitional zone; ^fCoastal savanna; ^gForest zone.

35% reduction in yield under rainfall conditions due to moisture limitations, highlighting a substantial water-related yield gap and opportunities for improved management (Nargund et al., 2024). However, Zhao et al. (2025a) reported poor agronomic management to account for approximately 86% of yield gaps, with climate and soil constraints playing a minimal role. This underscores the importance of improved agronomic practices, such as timely sowing, and nutrient amendments to narrow yield gaps.

4.1.1.1 Climate variability

Climate variability poses a major threat to soybean production in Ghana through rising temperatures, erratic rainfall, and increased drought frequency (Ntiamoah et al., 2022; Mirzabaev et al., 2023). The changes in weather disrupt crop calendars, intensify pest and disease pressure, reduce soil moisture availability, and decrease yield (Brown et al., 2015; Ntiamoah

et al., 2022), which disproportionately affected smallholder farmers, particularly in developing countries (Touch et al., 2024).

At the global level, recent analysis suggests that sowing date, water availability and climate stress, particularly El Niño-Southern Oscillation (ENSO)-related soil moisture variability are major drivers of soybean yield variability and yield gaps across major production regions (Hamed et al., 2023).

The seasonal timeline for soybean production in savanna and transitional agro-ecological zones are indicated in Table 5. In northern Ghana (Figure 2), where approximately 96% of national soybean production occurs is projected to experience temperature increases of 1.0–3.0 °C by mid-century and 2.3–5.3 °C by the end of the century (WBG, 2021; Touch et al., 2024). This aligns with Awuni et al. (2023) three-year (2017–2019) SMART Farm weather data across three locations in northern Ghana at Manga, Nyankpala, and Wa (Table 6). This may have significant impact not only on soybean production but rain-fed agriculture in general which dominates the region with minimal use of functional

TABLE 5 Seasonal soybean production timelines across the Savanna and transitional agro-ecological zones of Ghana.

Months	Savanna zones (SZ)				Transitional zone (TZ)			
	LP	PE	CM	HT	LP	PE	CM	HT
Jan								
Feb								
Mar								
Apr								
May								
Jun								
Jul								
Aug								
Sept								
Oct								
Nov								
Dec								

LP, land preparation; PE, planting and establishment; CM, crop maintenance; HT, harvesting and threshing.

Orange shades represent the timelines for key agronomic activities - land preparation (LP), planting and crop establishment (PE), crop maintenance (CM), and harvesting and threshing (HT) - as determined by the agroecological zone of production.

irrigation systems (<2%) (Hatfield et al., 2011; MacCarthy et al., 2022; Tuebner and Nicely, 2023). Rising temperatures have been shown to reduce soybean yields primarily by decreasing pod number and seed weight (Sharma et al., 2022). Although elevated CO₂ concentrations may enhance photosynthesis and water-use efficiency, net yield response remains location-specific based on interacting environmental and management factors (MacCarthy et al., 2022; Ekele et al., 2025).

Seasonal variations in rainfall and temperature have been reported to impact directly on soybean yield, particularly under rainfed production. Water deficits during critical growth stages, especially flowering and seed filling, are known to limit pod formation, reduce seed size, and lower grain yield (Sinclair and Vadez, 2012; Hartman et al., 2011). In a three-year (2017 to 2019) study with “Jenguma” across three locations (Manga, Nyankpala, and Wa) in Northern Ghana, dry spells were recorded in 2017 and 2019 (Table 6). In this study, the greatest rainfall deficits were recorded at Nyankpala (-127.1 mm) and at Wa (-105 mm) in 2017, while the average temperature increased up to 1.5 °C, could trigger an estimated yield loss for the “Jenguma” between 10–45%, depending on the severity and timing of the stress (Table 7).

Rainfall deficits related to soybean growth phenology are critical. For instance, in 2017, rainfall deficits occurred across the three locations between August–September in 2017, aligning with flowering and early pod set (Table 6). A similar trend occurred at Manga in 2019, while Nyankpala experienced deficits during the vegetative growth stages. However, Wa had dry periods in October coinciding with maturity and seed filling. Such alignment of drought during reproductive stages magnifies yield loss compared with stress occurring during vegetative growth. This coincidence at sensitive reproductive growth stages suggests potential yield reductions.

Using the observed seasonal rainfall and temperature variability relative to the 30-year average, conservative estimate of potential yield loss can be projected (Table 7). Table 7 was calculated from a simple climate-crop impact assessments empirical model as:

$$YL(\%) = a |D_r| + b\Delta T$$

Where:

YL = projected yield loss (%).

D_r = rainfall deficit (mm) relative to normal.

ΔT = temperature increase (°C).

a = rainfall sensitivity coefficient.

b = temperature sensitivity coefficient.

Where:

a = 0.20 % yield loss per mm rainfall deficit per 10 mm.

b = 8% yield loss per °C temperature increase.

So, the operational form becomes:

$$YL(\%) = 0.02 |D_r| + 8\Delta T$$

These results align with studies across the West African savanna sub-region where soybean yields under rainfed conditions are highly sensitive to intra-seasonal dry spells (Tadele, 2017), confirming the vulnerability of smallholder systems to climate variability. Additionally, water stress and elevated seasonal temperatures increase the potential yield loss. The effects of rising temperatures increase crop phenology, reduce duration of pod filling and seed maturation, and may increase evapotranspiration demand, further limiting soil water availability (Hartman et al., 2011). The combined effects of erratic rainfall and increasing temperatures create compounding stress, with significant consequences for reduction in yield potential.

While some models suggest potential for yield increase or stability in specific regions due to better growing conditions (Zhao et al., 2025b), others project significant declines, up to 30–50% due to intense heat, drought, and shortened growing cycles (Eze et al., 2022; Yu et al., 2021).

4.1.1.2 Soil fertility and nutrient limitations

A recent crop-model and statistical analysis showed how non-biophysical factors, such as water management and weed control contributed to historical stagnation or decline of soybean yields in Japan, despite modest potential increases (Kobayashi et al., 2026). Low soil fertility is a major constraint to soybean productivity in Ghana. Many soils are acidic and deficient in essential nutrients such as phosphorus (P), potassium (K), boron (B), and molybdenum (Mo), limiting nodulation, nitrogen fixation, and yield formation (Buri et al., 2005). Declining soil organic matter further reduces nutrient availability and soil health (Singh et al., 2024). This aligns with Awuni et al. (2023) three-year (2017–2019) SMART Farm soil fertility data across three locations in northern Ghana at Manga, Nyankpala, and Wa (Table 8).

Research on high-yielding soybean systems indicated fields with low yield gaps exhibited more favorable nitrogen uptake and balance, suggesting integrated nutrient management could directly influence soybean productivity and the magnitude of yield shortfall (Angelozzi et al., 2026). A meta-analysis confirms

TABLE 6 Total seasonal monthly rainfall and mean temperature deviations from the 30-yr average for Manga, Nyankpala, and Wa in Ghana's northern savannas (2017–2019).

Location	Month	Rainfall and temperature deviation from 30-yr average							
		Rainfall (mm)				Temperature (°C.)			
		2017	2018	2019	30-yr avg.	2017	2018	2019	30-yr avg.
		-----mm-----				-----°C-----			
Upper East Region	May	-17.8	29.0	14.6	90.0	0.9	0.7	0.4	29.6
	June	71.0	3.0	9.4	124.0	1.3	0.5	1.2	27.5
Manga	July	56.1	9.5	74.4	190.0	1.1	0.5	0.7	26.0
	Aug.	-11.6	11.8	-37.2	244.0	1.7	0.3	0.3	25.5
Eastern Sudan	Sept.	-46.5	51.0	-9.5	164.0	1.6	-0.1	0.7	26.0
	Oct.	-20.7	15.5	112.3	52.0	0.9	-0.5	-1.3	27.6
Savanna (ESS)	Nov.	-3.2	-4.9	-3.9	5.0	0.6	-0.9	-0.8	27.9
Total/Mean		-27.3	114.9	160.1	869.0	1.2	0.1	0.2	27.2
Northern Region	May	-69.9	-32.7	-2.1	123.0	2.2	1.3	2.3	28.9
	June	37.9	-76.7	-19.5	149.0	1.5	1.9	1.8	27.2
Nyankpala	July	144.8	6.2	-21.6	156.0	0.6	1.5	1.8	26.2
	Aug.	-65.0	105.5	-124.7	185.0	0.4	1.5	0.9	26.0
Opened Guinea	Sept.	-119.4	43.6	59.2	225.0	0.7	1.5	1.5	26.2
	Oct.	-58.7	9.3	52.1	99.0	0.7	1.0	0.8	27.4
Savanna (OGS)	Nov.	3.2	-11.0	-2.4	11.0	1.0	1.0	1.6	28.5
Total/Mean		-127.1	44.2	-59.0	948.0	1.1	1.4	1.5	27.2
Upper West Region	May	9.9	13.1	75.4	128.0	2.0	1.3	1.0	28.0
	June	79.2	5.3	-34.0	138.0	1.1	1.2	1.0	26.5
Wa	July	-21.0	182.6	54.5	166.0	0.8	0.2	0.7	25.6
	Aug.	-17.4	21.0	35.2	188.0	0.7	0.1	0.3	25.3
Western Sudan	Sept.	-96.7	71.8	-19.9	205.0	1.2	0.1	0.8	25.4
	Oct.	-52.4	-35.2	146.4	89.0	0.9	0.0	-0.7	26.7
Savanna (WSS)	Nov.	-6.6	-8.1	-10.0	11.0	0.7	-1.1	-1.1	27.6
Total/Mean		-105	250.5	247.6	925.0	1.1	0.3	0.3	26.4

Data Credit: Awuni et al. (2023). ESS, Eastern Sudan Savanna; OGS, Open Guinea Savanna; WSS, Western Sudan Savanna.

that nutrient management, particularly of P, K, and inoculants, and correct sowing timing significantly increase yields, indicating technology bundle could reduce local yield gaps if adoption barriers are addressed (Omondi et al., 2023).

These findings align with integrated soil fertility management, including liming to maintain soil pH near 6.0–6.5, application of *Bradyrhizobium* inoculants to enhance biological nitrogen fixation

(Awuni et al., 2020, Awuni et al., 2023), and balanced P and K fertilization (Awuni et al., 2024). Phosphorus is particularly critical for rhizobial nodulation, however, its availability in acidic soils is often limited due to fixation (Awuni et al., 2020). Combining mineral fertilizers with organic amendments (e.g., manure, compost, crop residues, and FertiSoil) improves soil organic carbon, nutrient availability, and long-term sustainability.

TABLE 7 Estimated yield reduction due to rainfall and temperature variability in Manga, Nyankpala and Wa across two seasons (years).

Site	Year	Rainfall deficit (mm)	Temperature increase (°C)	Projected yield loss (%)
Manga	2017	-27.6	1.2	20–25
Nyankpala	2017	-127.1	1.1	35–45
Wa	2017	-105.0	1.1	30–40
Manga	2019	- moderate	0.2	10–15
Nyankpala	2019	-59.0	1.5	25–35

Data Credit from Awuni et al. (2023).

TABLE 8 Soil properties and fertility status at 0–15 cm soil depth average across three years (2017–2019) for Manga (ESS), Nyankpala (OGS), and Wa (WSS) in Ghana's northern savannas.

Soil properties	Manga, (ESS)		Nyankpala, (OGS)		Wa, (WSS)	
	Value	Interpretation	Value	Interpretation	Value	Interpretation
Physical						
Soil texture, %						
Sand	75.0	–	67.0	–	87.0	–
Silt	21.0	–	29.0	–	10.0	–
Clay	4.0	–	4.0	–	3.0	–
Classification	–	Sandy loam	–	Sandy loam	–	Loamy sand
Chemical						
Mean pH	5.2	Strong acidity	5.4	Strong acidity	6.0	Moderately acidic
Buffer pH	6.79	–	6.78	–	*6.81	–
P, mg kg ⁻¹	19.0	Medium	24.0	Medium	11.0	Low
K, mg kg ⁻¹	41.0	Very low	56.0	Low	43.0	Very low
Ca, mg kg ⁻¹	427.0	Medium	473.0	Medium	212.0	Medium
Mg, mg kg ⁻¹	43.0	Low	53.0	Medium	49.0	Low
S, mg kg ⁻¹	9.0	Low	10.0	Low	7.0	Low
B, mg kg ⁻¹	0.1	Very low	0.2	Low	0.1	Very low
Cu, mg kg ⁻¹	0.4	Low	0.3	Low	0.3	Low
Fe, mg kg ⁻¹	57.0	Medium	51.0	Medium	34.0	Low
Mn, mg kg ⁻¹	49.0	Medium	51.0	Medium	43.0	Medium
Zn, mg kg ⁻¹	3.7	Medium	1.1	Low	0.7	Low
Na, mg kg ⁻¹	21.0	Very low	14.0	Very low	9.0	Very low
Salinity, ds/m	0.12	Very low	0.13	Very low	0.13	Very low
OM, %	0.5	Very low	0.6	Very low	0.7	Very low
CEC, meq/100g	4.1		4.7		3.2	
NO ₃ -N, mg kg ⁻¹	9.0		4.0		2.0	
Al, mg kg ⁻¹	245.0		344.0		326.0	

Data Credit: Awuni et al. (2023). CEC, cation exchange capacity; OM, organic matter. Soil analysis by Waypoint Analytical Inc., Memphis, TN (USA). ESS, Eastern Sudan Savanna; OGS, Open Guinea Savanna; WSS, Western Sudan Savanna.

4.1.2 Socioeconomic constraints

Socioeconomic constraints in soybean production primarily include high input costs (fertilizer, seeds), limited access to credit, inadequate marketing infrastructure, and low technical knowledge among farmers (Nget et al., 2021). Other key challenges involve land tenure issues, poor transportation, and gender inequality in accessing resources (Nget et al., 2021). This highlights socioeconomic and management constraints on closing yield gaps at national scale.

4.1.2.1 Limited mechanization and technology adoption

Limited access to mechanization significantly constrains soybean expansion among smallholders and commercial farmers. Planting and harvesting remain the most labor-intensive and yield-limiting operations (Addae-Frimpomaah et al., 2022; Tabdeen et al., 2025). In northern Ghana, high temperatures, low humidity, and dry winds accelerate pod shattering after maturity, particularly in

the absence of timely mechanized harvesting (Bara et al., 2013). Low plant clearance at maturity further complicates mechanization, discouraging large-scale production and contributing to the predominance of small farm sizes (<2 ha).

Technology adoption among soybean farmers is uneven and influenced by wealth, farm size, gender, and access to extension services (Anang and Zakariah, 2022). Crop residue removal for livestock feed during the dry season further undermines soil fertility by reducing organic matter inputs, perpetuating a cycle of declining productivity (Antwi-Agyei et al., 2023).

4.1.2.2 Inadequate infrastructure

Poor rural infrastructure, particularly road networks, increases transaction costs, limits market access, and exacerbates post-harvest losses (Agbanu and Dzansi, 2024). Farmers are often forced to sell to middlemen at low prices due to poor connectivity, lack of standardized grading systems, and limited storage and processing facilities. Inadequate infrastructure has also constrained domestic

processing capacity with some processing firms operating below capacity or halting operations (Frimpong, 2024; Taylor and Tuebner, 2024). Although infrastructure alone is insufficient for poverty reduction, it highlights the need for complementary institutional and market reforms (Kaiser and Barstow, 2022).

4.1.2.3 Market access and price volatility

Soybean farmers in Ghana face price volatility and market uncertainty, which discourage long-term investment in productivity-enhancing technologies. Export restrictions intended to protect domestic supply have often disincentivized production, encouraged smuggling, and fragmented value chains (Frimpong, 2024). While international markets exist, fragmented supply systems, weak quality control, and limited infrastructure hinder smallholder participation (Jia et al., 2025). The absence of transparent pricing and standardized grading further disadvantages farmers and reinforces dependency on intermediaries, reducing incentives for yield improvement.

4.1.3 Biotic constraints

Soybean yield gap reported across Malawi, Zambia, and Mozambique identified cultivar choice (~64%), seed rate (~50%), and disease damage, particularly soybean rust (~36%), as major limiting factors contributing to yield gaps in smallholder system (Omondi et al., 2024). The authors argued that tailoring context-specific interventions include improved cultivars, better seed quality, and effective weed management to help close these yield gaps.

4.1.3.1 Limited genetic diversity and cultivar suitability

Persistent yield gaps are partly attributed to limited genetic diversity and suboptimal cultivar selection (NVRRC, 2019). Although current cultivars possess desirable traits such as disease resistance and drought tolerance (Denwar et al., 2019), many exhibit low pod clearance, increasing harvest losses and limiting mechanization (Tkachuk, 2019). Pod height is influenced by genotype, environment, and management ($G \times E \times M$), including planting density, row spacing, planting date, and tillage (Tkachuk, 2019).

Large-scale farmers increasingly demand high-clearance cultivars compatible with mechanized harvesting (Bara et al., 2013; Tabdeen et al., 2025). The introduction of diverse foreign germplasm, including through initiatives such as the Pan-African soybean varietal trials of the Soybean Innovation Laboratory, offers opportunities to strengthen local breeding programs and expand cultivar options.

4.1.3.2 Weed pressure

Soybeans are highly vulnerable to weed competition during early growth stages, making timely and integrated weed management essential (Paul et al., 2024). Integrated weed management (IWM) combines preventive, protective, and control strategies across the production cycle to suppress weed pressure and

reduce reliance on repeated interventions. Practices such as crop rotation, optimal planting density, narrow row spacing, herbicide use, mulching, and intercropping enhance crop competitiveness and yield stability (Riemens et al., 2022; Paul et al., 2024). In northern Ghana, nine major broadleaf weeds, four grassy weeds, and two sedge species have been documented in soybean fields (Lamprey et al., 2015).

4.1.3.3 Diseases

Soybeans in Ghana are affected by multiple fungal pathogens (Ansah et al., 2023), including soybean rust (*Phakopsora pachyrhizi*), myrothecium leaf spot (*Paramyrothecium roridum*), frog-eye leaf spot (*Cercospora sojina*), aerial blight (*Rhizoctonia solani*), and septoria brown spot (*Septoria glycines*) (Awuni et al., 2021). Soybean rust remains the most economically damaging disease, while recently reported diseases require further epidemiological study (Ekele et al., 2025). Disease severity is influenced by environmental conditions, cultivar resistance, crop rotation, and management practices (Kalaitzandonakes et al., 2019).

4.1.3.4 Insect pests

The pod-sucking bug complex, which include *Nezara viridula*, *Riptortus dentipes*, *Aspavia armigera*, and *Clavigralla tomentosicollis*, represents the most significant insect constraint to soybean production in Ghana, particularly in savanna regions (Abdulai, 2018; Awuni et al., 2021; Nboyine et al., 2021). Defoliators, stem feeders, and seed borers further reduce yield and seed quality (Awuni et al., 2021; Nboyine et al., 2021). Integrated pest management strategies with resistant cultivars, optimized planting dates, cultural practices, and judicious insecticide use, are essential for sustainability.

4.2 Proposed strategies and implementation roadmap for sustainable soybean production in Ghana

Achieving sustainable soybean production in Ghana requires coordinated interventions that address agronomic inefficiencies, yield and technology gaps, climate risks, weak market linkages, and policy constraints. The following priority strategies span production systems, value chains, and governance frameworks.

4.2.1 Strengthening farmer and extension capacity

Strengthening agricultural extension services is critical for improving soybean productivity. Targeted training for smallholder farmers and Agricultural Extension Agents (AEAs) should focus on modern agronomic practices (MAPs). These include land preparation, optimal planting dates and methods, row spacing, fertilizer and inoculant application, integrated pest (insects, weed and disease) management, and post-harvest handling (Atanga, 2023).

Evidence from multi-year, multi-location SMART farm trials in Ghana recommends a seeding rate of approximately 333,333 seeds ha⁻¹

(Awuni et al., 2020; Awuni et al., 2023; Awuni et al., 2024), calibrated based on cultivar maturity, row spacing, and seeds per hill, assuming an 80% plant vigor threshold for profitability. Capacity-building programs could promote the adoption of certified seeds, non-shattering and climate-resilient cultivars, and biofertilizers to improve soil fertility and yields.

Participatory training models, particularly Farmer Field Schools (FFS), facilitate experiential learning, farmer-led experimentation, and localized adaptation of sustainable practices (Davis et al., 2012). Enhancing AEAs' technical and digital competencies is equally important to support scalable advisory systems, including mobile-based platforms that provide real-time agronomic and market information (Mutuma et al., 2023).

Reducing soybean yield gaps requires strengthening Ghana's National Agricultural Research and Extension Services (NARES) and breeding institutions to develop and disseminate high-yielding, drought- and disease-resistant, and high-clearance cultivars adapted to diverse agro-ecological zones (Tkachuk, 2019; Baffour-Ata et al., 2024). Breeding programs should integrate farmer and processor preferences, including early maturity, non-shattering traits, large seed size, high protein content, and pest resistance.

Participatory varietal selection programs (PVSPs) can accelerate technology adoption by ensuring new cultivars reflect farmer needs and local production conditions (Bara et al., 2013). Concurrent investments are needed to expand smallholder access to certified seeds, biofertilizers, and soil fertility management technologies. Further research on phosphorus and potassium optimization and inoculant performance across degraded soils remains essential due to widespread nutrient limitations (Awuni et al., 2023; Awuni et al., 2024; Touch et al., 2024).

4.2.2 Strengthening processing, storage and market linkages

Expanding domestic soybean processing capacity is essential for value-chain development. Public-private investment in small- and medium-scale crushing, storage, and processing facilities can reduce post-harvest losses while stimulating demand for value-added products such as soybean oil, soy beverages, and animal feed.

Improving soybean productivity among smallholder farmers requires improved post-harvest management, particularly grain storage. Significant losses of legumes and oilseeds occur during storage due to insect infestation, moisture fluctuations, and deterioration of seed quality (Kumar and Kalita, 2017). The use of hermetic storage technologies such as Purdue Improved Crop Storage (PICS) bags offers a promising solution for reducing these losses. These are triple-layer hermetic bags designed to create an airtight environment to limit oxygen availability and suppresses pest activity in storage without the use of chemical insecticides. The bags are widely promoted for smallholder farmers because of cost effectiveness, easy to use, and the ability to effectively preserve grain quality (Baributsa and Baoua, 2022).

Studies have shown that hermetic storage using PICS technology significantly reduces insect damage and weight loss in stored grain compared with conventional polypropylene or jute bags (Baributsa and Baoua, 2022). PICS bags have been reported to experience less

than 3% weight loss compared with over 40% weight loss in traditional bags due to suppressed insect infestation (Oyewole et al., 2025). Additionally, hermetic storage helps maintain seed quality and germination capacity, which is critical for crops such as soybean that are often stored for both consumption and planting (Baributsa and Baoua, 2022). Evidence suggests that soybeans stored in hermetic bags maintain germination and seed quality even under high humidity conditions (Baributsa and Baoua, 2022), suggesting the technology can effectively protect planting materials and food stocks.

These findings highlight the potential of hermetic storage technologies to complement agronomic improvements in closing soybean yield gaps by reducing post-harvest losses and improving the economic returns of smallholder farmers.

Improving transport logistics and rural infrastructure will enhance market access and supply chain efficiency. Establishing and enforcing national soybean grading and quality standards is critical to improving price transparency and market competitiveness (Mutuma et al., 2023). Experiences from Ethiopia's Integrated Agro-Industrial Parks (IAIPs), highlight the potential of agro-industrial clustering to drive productivity and employment to support smallholders and stimulated agribusiness investment (Boru et al., 2025).

Strengthening farmer cooperatives, farmer-based organizations (FBOs), and nucleus-outgrower schemes (NOS) can improve collective bargaining power, facilitate access to credit and inputs, and reduce transaction costs, thereby integrating smallholders more effectively into soybean value chains.

4.2.3 Enhancing climate resilience

Climate change adaptation must be integrated into soybean development strategies. Promoting drought- and heat-tolerant cultivars alongside strengthening climate information services (CIS) will enable farmers to optimize planting and management decisions based on seasonal forecasts and early warning systems (Baffour-Ata et al., 2024).

Sustainable land management practices, including mulching, crop rotation, agroforestry, and conservation agriculture, should be expanded to improve soil health and production stability. Fertilizer use guided by the 4R (right source, rate, time, and place) nutrient stewardship framework can enhance nutrient-use efficiency while minimizing environmental losses (Hatfield et al., 2011). These practices should be complemented by reduced tillage, cover cropping, and no-till systems.

Integrated pest management (IPM) approaches must be prioritized to reduce chemical pesticide dependence, lower production costs, and mitigate environmental risks. Improved water management strategies, including rainwater harvesting and water-efficient soybean cultivars, will further strengthen resilience to rainfall variability.

4.2.4 Policy support and strategic investment

Sustained policy commitment and targeted investment are essential to unlock Ghana's soybean potential. Priority interventions include expanding access to affordable credit, providing targeted input

subsidies for certified seed and biofertilizers, and strengthening mechanization services for smallholders. Addressing land tenure insecurity is critical for encouraging long-term investments in soil fertility and productivity.

Market-stabilization policies that balance domestic supply with export opportunities can reduce price volatility and improve farmer confidence. Strengthening FBOs as aggregation and marketing platforms will enhance price negotiation and reduce reliance on intermediaries. Expanding soybean utilization in public procurement programs, including school feeding initiatives, can stimulate domestic demand and provide reliable markets for producers.

Continued support for regional and national initiatives, such as the West Africa Food System Resilience Program (FSRP), FAO's One Country One Priority Product (OCOP), and National Support to Soybean Development Program, will strengthen institutional capacity, improve smallholder livelihoods, and enhance national food and nutrition security. An implementation pathway for a sustainable soybean production in Ghana is presented in Table 9.

4.2.5 Theoretical implications and practical applications

This study highlights the multifaceted drivers of soybean yield gaps among smallholder farmers. Consistent with our findings from recent evidence from Ghana's interior savanna, phosphorus (P) and potassium (K) deficiencies, along with suboptimal inoculation practices, remain pivotal constraints on soybean productivity due

to their effects on nodulation, biological nitrogen fixation, and crop growth (Awuni et al., 2024). These nutrient limitations echo across Sub-Saharan Africa, where yield gap decomposition studies identified soil fertility and plant nutrition as primary limiting factors, often surpassing the effects of variety choice and seed rate (Omondi et al., 2024).

From a theoretical perspective, our findings refine yield gap frameworks by highlighting the interplay between soil biophysical constraints, input accessibility, and farmer decision-making in resource-limited environments. This aligns with recent agronomic theory that suggests smallholders' adaptive responses, such as selective use of inoculants and soil amendments, reflect risk-sensitive innovation strategies rather than mere technology adoption deficits. Additionally, research on inoculant response variability across cultivars suggests that genotype-microbe compatibility exerts a strong influence on yield outcomes, which supports incorporating genotype-specific management into smallholder yield gap analyses (Awuni et al., 2020; Abdul-Aziz et al., 2025).

Enhancing innovation adoption theory, our results converge with socio-economic analyses showing that farm characteristics, access to extension, and institutional support drive inoculant uptake and, by extension, yield improvement potential among Ghanaian smallholders (Anang et al., 2023). This highlights how agronomic innovations do not diffuse uniformly but interact with local socio-institutional environments, a crucial insight for designing sustainable intensification strategies.

TABLE 9 Implementation roadmap for sustainable soybean production in Ghana.

Strategic priority	Key actions	Lead actors	Time horizon	Expected outcomes/indicators
Farmer and Extension Capacity Building	Scale Farmer Field Schools (FFS); train AEAs on MAPs, digital advisory tools, and post-harvest management	MoFA, AEAs, NGOs, NARES	Short-term (1–3 yrs)	≥30% increase in MAPs adaptation; improved farmer knowledge; reduced field and post-harvest losses
Genetic Improvement and Seed Systems	Develop and release high-yielding, drought-tolerant, non-shattering, high-clearance cultivars; expand certified seed systems	NARES, Universities, NVRRC, Seed Companies	Medium-term (3–5 yrs)	Yield increase toward 2.5–3.0 t ha ⁻¹ ; expanded cultivar choice; reduced harvest losses
Soil Fertility and Input Access	Promote inoculant use, liming, and balanced P–K fertilization; strengthen input distribution networks	MoFA, NARES, Private Input Dealers, Donors	Short–Medium-term	Improved nodulation; higher soil organic matter; increased nutrient-use efficiency
Mechanization and Harvest Efficiency	Support access to planters, harvesters, and threshers; promote high-clearance cultivars	Private Sector, MoFA, NARES, Farmer Cooperatives	Medium-term	Reduced labor costs; lower pod shattering losses; expanded farm sizes
Market Access and Value Addition	Invest in local processing, storage (e.g., PICS bags), and logistics; implement national grading standards	Private Sector, MoTI, MoFA	Medium-term	Reduced PHL; increased domestic processing; improved farm-gate prices
Climate Resilience and Sustainability	Promote climate-resilient cultivars; strengthen climate information services; scale IPM and conservation agriculture	MoFA, Meteorological Agency, AEAs	Medium–Long-term (5+ yrs)	Improved yield stability; reduced climate risk exposure; lower pesticide use
Farmer Organization and Aggregation	Strengthen FBOs, cooperatives, and nucleus-outgrower schemes	MoFA, NARES, NGOs, Private Sector	Short–Medium-term	Improved bargaining power; better access to credit and markets
Policy and Strategic Investment	Align soybean policies as a “political crop” with input subsidies, credit schemes, school feeding programs, and export management	Government, Development Partners	Long-term	Stable markets; increased investment; contribution to food security and rural employment

MAPs, modern agronomic practices; PHL, post-harvest losses; MoTI, Ministry of Trade and Industry; NARES, National Agricultural Research and Extension Systems.

Practically, calibrated inoculation strategies tailored by cultivar and soil condition can substantially increase yields, as demonstrated by significant grain yield improvements at optimized *Bradyrhizobium* inoculant rates, albeit with variation across seasons (Awuni et al., 2020; Abdul-Aziz et al., 2025). Additionally, lessons from broader regional soybean research indicate the prioritization of certified varieties, appropriate seeding rates, and disease management can further narrow yield gaps, especially when coupled with nutrient management tailored to site-specific soil fertility profiles (Omondi et al., 2024).

From a policy and extension context, this review advocates for integrated input bundles (certified seed + inoculant + fertilizers) coupled with robust advisory services that address on-farm variability and farmer constraints (Awuni et al., 2020), including potential lime application (Awuni et al., 2023; Awuni et al., 2024). Targeted support should be informed by both crop management research and socio-economic determinants of adoption. Finally, aligning national agricultural programs with soybean as a “political crop” can drive sustainable intensification that enhances resilience and economic returns in Ghana’s soybean systems.

5 Conclusion

Sustainable soybean production in Ghana presents a transformative opportunity to enhance national nutrition, strengthen rural livelihoods, restore soil fertility, and advance both national and international development priorities. The realization of this potential, however, requires deliberate political commitment to position soybean as a strategic “political crop”, supported by a coordinated and integrated approach across agronomy, genetics, infrastructure, markets, and community engagement. Expanding access to certified seeds and inoculants will equip smallholder farmers with high-yielding, climate-resilient cultivars and biofertilizers. Promoting conservation agriculture practices, such as no-till farming, crop rotation, and integrated pest management, can enhance soil health and long-term productivity. Strategic investments in rural roads, storage facilities, and small- to medium-scale processing enterprises are essential to reduce post-harvest losses, improve market access, and stimulate value addition. Strengthening farmer-based organizations and nucleus-outgrower schemes will expand access to credit, mechanization, training, and reliable market linkages, intentionally empowering women and youth. Scaling up early warning systems through localized weather stations, and agroforestry initiatives to enhance agroecological networks will help farmers adapt to climate variability and sustain productivity. Through coordinated implementation of these measures, Ghana can significantly increase soybean output, build resilient rural economies, promote inclusive growth, establish competitive and sustainable soybean production as an export hub in sub-Saharan Africa. Closing soybean yield gaps in Ghana requires an approach that integrates agronomic innovation, adaptive management, and

market-oriented interventions. This study provides a framework for both theoretical understanding and practical application, offering a roadmap to enhance smallholder productivity, livelihoods, and sustainable agricultural intensification across Sub-Saharan Africa.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

GA: Project administration, Validation, Formal analysis, Conceptualization, Writing – review & editing, Data curation, Software, Methodology, Writing – original draft, Visualization, Investigation. PA: Visualization, Validation, Conceptualization, Methodology, Writing – review & editing, Investigation. GM: Investigation, Writing – review & editing, Visualization, Methodology, Validation, Conceptualization. JN: Validation, Visualization, Formal analysis, Conceptualization, Methodology, Writing – review & editing, Investigation. FA-F: Conceptualization, Investigation, Writing – review & editing, Validation, Visualization, Methodology. FK: Validation, Investigation, Supervision, Visualization, Resources, Writing – review & editing, Conceptualization. DD: Visualization, Conceptualization, Methodology, Investigation, Validation, Supervision, Writing – review & editing. DR: Resources, Visualization, Formal analysis, Software, Conceptualization, Investigation, Validation, Writing – review & editing, Supervision, Project administration, Funding acquisition, Methodology.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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