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Evaluation of productivity and compatibility of sorghum with velvet bean and cowpea in intercrop system.

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DEDICATION

I, Grevis Ranjisi, the writer of this dissertation, clearly and faithfully confirm that, this piece of work was done personally and there is no plagiarism. I dedicate this work to my parents Ephert Ranjisi and Jenet Nyamawende, and my younger brother, Fleture Ranjisi for patience, support and encouragement during the duration of research program.

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Abstract

Addressing sustainable intensification in Zimbabwe's semi-arid regions (300-500 mm rainfall; sandy loam soils), this research evaluated sorghum-legume intercropping systems through field experiments, assessing three *Sorghum bicolor* cultivars (Dwarf Yellow Milo, Pioneer 84G62, Gandam) and two legumes (cowpea, velvet bean). The objectives of the study were to assess differential compatibility between velvet bean and cowpea when intercropped with sorghum; evaluating whether cereal-legume intercropping enhances the land equivalent ratio (LER) and examining how sorghum plant stature influences legume yield performance in intercrop systems. Employing a slope-blocked randomized design across 11 treatments with species-specific spacing (sorghum 75×5 cm; legumes 45×15 cm). Key findings revealed cowpea's exceptional compatibility with dwarf sorghum, yielding peak system productivity (1,357.9 kg/ha) and land efficiency (LER=1.52) through growth habit control and nitrogen facilitation. Conversely, velvet bean's competitive dominance (AI=+0.61) depressed outputs (1,087.7 kg/ha) via light interception and moisture rivalry, while dwarf sorghum minimized competition (height reduction to 114 cm). These results critically establish particularly cowpea-dwarf sorghum configurations as essential for climate-resilient smallholder agriculture, necessitating germplasm dissemination and seasonal alignment for scalable adoption.

Key words: Sorghum-legume intercropping; Land Equivalent Ratio (LER); Competitive dynamics; Dwarf sorghum cultivars; Semi-arid smallholder systems; Resource partitioning efficiency

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List of acronyms

AI- Aggressivity Index

ATER- Area-Time Equivalent Ratio

BNF-Biological Nitrogen Fixation

CEC-Cation Exchange Capacity

C_4- C4 Photosynthesis

GDP-Gross Domestic Product

Ha-Hectare

Kg-Kilogram

LER-Land Equivalent Ratio

Nater-Normalized Area-Time Equivalent Ratio

1.0 CHAPTER ONE: INTRODUCTION

1.1 Background

Agriculture employs and sustains over 70% of Zimbabwe's population, contributing approximately 17% to national GDP (Mupambwa et al., 2021; Parwada & Chinyama, 2021). Most farmland lies in semi-arid zones characterized by erratic precipitation, diminished crop yields, and infertile soils. Implementing sustainable cropping methods represents a critical strategy for enhancing farm output, restoring soil health, and strengthening food security (Musyimi et al., 2022). Cereal-legume intercropping stands out as a practical approach, boosting climate resilience while enhancing soil fertility and resource efficiency (Mwajoha, 2017).

Sorghum (*Sorghum bicolor*) serves as a vital food security crop in Zimbabwe's drought-prone regions. This small-grain cereal tolerates arid conditions with under 500mm annual rainfall, unlike maize which requires at least 700mm to mature (Morgan et al., 2019). Annual production reaches 250,000 tonnes, feeding millions (Parwada & Chinyama, 2021). Nutritionally, sorghum provides up to 12% dietary fiber, 70–80% carbohydrates by weight, and essential micronutrients like iron and magnesium (Aboah & Setsoafia, 2022). Beyond food security, it supports economic stability through local markets, animal feed, and brewing industries (Adam et al., 2025), offering significant value to smallholders.

Legumes like cowpea (*Vigna unguiculata*) and velvet bean (*Mucuna pruriens*) enhance nutritional and ecological sustainability in cereal systems. Velvet bean fixes atmospheric nitrogen symbiotically, contributing up to 200 kg N/ha yearly. This helps enrich soil organic matter and reduces synthetic fertilizer dependence (Afridi et al., 2024). Cowpea delivers high protein (23–25%) and nutrient-rich leaves abundant in vitamin A, iron, and calcium (Yumbya, 2025), directly combating malnutrition (Abiye et al., 2023). Both legumes suppress weeds, conserve soil moisture, and diversify farm income (Abiye et al., 2023), strengthening system resilience. Their soil-enriching and nutrient-dense properties support integrated agroecological approaches to address Zimbabwe’s intertwined challenges of climate vulnerability and food insecurity (Haripo et al., 2023; Parwada & Chinyama, 2021).

Integrating legumes with sorghum in intercropping configurations maximizes land productivity and improves farmer profitability (Rahman, 2021). Studies by Boukar et al. (2013) show cereal-legume intercrops achieve land equivalent ratios (LER) as high as 1.8—signifying an 80% productivity gain over monocultures. Such systems consequently enable smallholders in resource-limited semi-arid zones to boost food output, enhance household nutrition, and fortify economic resilience (Boukar et al., 2013; Brilli et al., 2024).

In Zimbabwe's drylands, sorghum, a resilient cereal crop, plays a vital role in ensuring food security (Dzvene et al., 2023; Parwada & Chinyama, 2021). Early-maturing sorghum varieties, particularly those with differing heights, create unique opportunities to enhance productivity through legume integration. Nitrogen-fixing legumes like velvet bean and cowpea, recognized for their stress tolerance, show potential for boosting sorghum yields and overall system output (Favre et al., 2019; Sibhatu, 2016). Nevertheless, research remains limited regarding the compatibility and productivity of these legumes when intercropped with early-maturing sorghum cultivars of varying statures.

Intercropping systems demonstrably surpass monocultures by enhancing biodiversity, improving resource-use efficiency, and increasing total productivity (Gadallah & Ragheb, 2015; Gebregziabher et al., 2015). Cereal-legume combinations derive particular advantages from complementary growth patterns and resource sharing: legumes fix atmospheric nitrogen and enrich subsurface fertility, while cereals primarily access nutrients in upper soil layers (Kangalawe et al., 2008). However, successful implementation in Zimbabwe requires locally relevant research to identify optimal crop pairings, planting configurations, and management strategies that maximize yield without compromising sustainability (Haripo et al., 2023).

Crop variety selection critically influences intercrop performance and compatibility. The interaction between early-maturing sorghum cultivars of different heights and intercropped legumes is heavily dependent on variations in canopy architecture, light capture efficiency, and competitive dynamics (Kangalawe et al., 2008; Karanja et al., 2017). Shorter sorghum varieties may enhance legume performance through improved light availability, whereas taller types risk overshadowing legumes, potentially suppressing their growth and nitrogen fixation capacity (Kinama et al., 2018; Kumaraswamy et al., 2024). Similarly, cowpea and velvet bean possess distinct growth habits and nutritional demands, affecting their compatibility with different sorghum cultivars and overall system functionality (Léonidas et al., 2024).

Addressing these interactions is especially crucial in Zimbabwe, where smallholder farming sustainability faces threats from soil degradation and declining yields. Understanding the productivity and suitability of intercropping diverse early-maturing sorghum statures with velvet bean and cowpea can facilitate the creation of resilient, sustainable cropping systems adapted to national agro-ecological conditions (Li et al., 2013; Ma et al., 2023; Matita et al., 2022). This research also aligns with Zimbabwe's broader goals of promoting climate-smart agriculture and enhancing smallholder farmer livelihoods.

1.2 Problem Statement

Smallholders in Zimbabwe's semi-arid regions face severe challenges soil degradation, erratic rainfall, and yield stagnation (Matita et al., 2022). Traditional sorghum monocropping exacerbates resource depletion during climate stress, failing to stabilize productivity (Misiko et al., 2008). While cereal-legume intercropping offers resilience, critical knowledge gaps persist regarding the agronomic viability of early-maturing, dwarf sorghum cultivars combined with multipurpose legumes like cowpea and velvet bean. Robust assessments of growth dynamics, yield synergies, and resource-use efficiency (light/water/nutrient partitioning) across agroecological zones remain absent; farmers consequently lack specialized methods to optimize intercrop systems due to insufficient localized evidence, hampering context-specific guideline development..

1.3 Justification

This study fills a critical gap in sustainable agricultural practices for Zimbabwe's semi-arid regions, where over 60% of smallholder farmers' livelihoods are threatened by climate variability and soil degradation (ZIMSTAT, 2022). By assessing early-maturing sorghum cultivars interplanted with cowpea (Vigna unguiculata) and velvet bean (Mucuna pruriens), the study directly addresses the urgent need for climate-resilient cropping systems that maximise resource use efficiency (Snapp et al., 2021). Recent data confirms that such legume-cereal combinations can increase soil nitrogen by 30–50 kg/ha annually while improving water-use efficiency by 25–40%, which is crucial in areas with less than 600 mm of rainfall (Mupangwa et al., 2023; Rusinamhodzi, 2023). According to Nyagumbo et al. (2020), the results will offer practical methods to increase yields by 20–35% in comparison to monocropping, thereby promoting food security and stabilising household income. Additionally, the emphasis on dwarf sorghum cultivars fills important knowledge gaps regarding compatibility with legume intercrops, guaranteeing fair distribution of nutrients and light (Chimonyo et al., 2023). Through alignment with SDGs 2 (Zero Hunger) and 13 (Climate Action) and Zimbabwe's Climate-Smart Agriculture Policy (2020–2024), this research provides scalable solutions to reduce environmental degradation and increase farm profitability (MoA, 2020; UN, 2015).

1.4 Objectives

1.4.1 Aim

To assess compatibility and productivity of cereal-legume intercrops among sorghum in combination with cowpea and velvet bean.

1.4.2 Specific objectives

1. To assess differential compatibility between velvet bean and cowpea when intercropped with sorghum.
2. To evaluate whether cereal-legume intercropping enhances the land equivalent ratio (LER).
3. To examine how sorghum plant stature influences legume yield performance in intercrop systems

1.4.3 Hypotheses (H0)

1. Velvet bean and cowpea do not show significant differences in compatibility with sorghum.
2. Cereal-legume intercropping does not significantly increase the land equivalent

ratio compared to sole cropping.

3. Sorghum plant stature has no significant influence on the productivity of intercropped legumes.

2.0 CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and Domestication of Sorghum and Legumes

Sorghum (*Sorghum bicolor* L.) traces its domestication to Northeast Africa (8,000–5,000 BCE), serving as a critical crop against food insecurity throughout history (Fukai & Midmore, 1993; Nyagumbo et al., 2020; Peoples & Herridge, 1990). Early agriculturalists selectively cultivated wild grasses for drought resilience. Research confirms its C_4 photosynthetic efficiency enables survival in harsh conditions (>35°C; <500 mm annual rainfall), establishing sorghum as a Sahelian staple (Musa et al., 2021). By 2000 BCE, trade facilitated its spread to India, China, and the Americas, where accelerated maturation and pest resistance emerged through adaptation (Mupambwa et al., 2021). In Zimbabwe, sorghum holds profound cultural and agricultural significance—forming the basis of *sadza* porridge and livestock feed. It sustains >60% of arid-region households where maize fails (Chimonyo et al., 2021). Farmer-preferred indigenous cultivars (e.g., Chibuku, Macia) yield 1.2–1.8 t/ha in poor soils, demonstrating generations of selective adaptation.

Legumes similarly reflect agricultural innovation. Cowpea (*Vigna unguiculata* L.) originated in West Africa's Sudanian savanna (~3,000 BCE) (Markos, 2023). Its rapid growth cycle (60–90 days) and nitrogen fixation (40–80 kg N/ha/year) proved vital for subsistence agriculture (Dzvene et al., 2023; Haripo et al., 2023). Sahelian archaeological evidence reveals its nutrient-rich grains (23–25% protein) and leaves (25–30% crude protein) supplied essential iron, zinc, and folate (Khagul, 2023). Velvet bean (*Mucuna pruriens* L.), domesticated separately in West Africa and Mesoamerica, became integral to Zimbabwean smallholder systems (Phiri et al., 2023). It replenishes soils (3–5 t/ha organic matter), suppresses weeds, and historically served as famine food following detoxification (roasting/soaking reduced toxic L-DOPA) (Osewe et al., 2023).

Centuries of farming observation revealed sorghum-legume synergies. Intercropping during droughts stabilized yields by 20–40%, attributed to legume shade moderating soil temperature/moisture (Degebasa et al., 2024). Modern agronomy confirms niche complementarity: sorghum's canopy shelters legumes from solar stress, while legume root exudates (e.g., flavonoids) enhance sorghum's phosphorus uptake via mycorrhizae (Takele et al., 2016; Yumbya, 2025). Soil analyses at Great Zimbabwe (1100–1450 CE) show elevated nitrogen—indicating premodern legume integration (Nhamo et al., 2017; Nyagumbo et al., 2020). Contemporary Matabeleland North smallholders maintain sorghum-cowpea intercrops, boosting child nutrition and household dietary diversity by 30% (Mupambwa et al., 2021; Phiri et al., 2023)

2.2 Nutritional and Economic Benefits of Sorghum-Legume Intercropping

Intercropping cereals and legumes enhances food security and dietary diversity in resource-limited regions plagued by nutrient deficiencies (Mupambwa et al., 2021; Phiri et al., 2023). Sorghum, a semi-arid staple, delivers substantial carbohydrates (70–80% content) alongside critical minerals like zinc (1.6 mg/100 g) and iron (4.4 mg/100 g) (Musyimi et al., 2022). Yet its protein quality remains constrained by tryptophan (0.5–1.0%) and lysine (1.5–2.0%) limitations (Raza et al., 2024; Rugheim et al., 2016). Cowpea and velvet bean counterbalance these gaps through high-quality protein (23–25% in cowpea) containing those limiting amino acids, plus provitamin A, calcium (60–80 mg/100 g), and folate (180–200 μg/100 g) (Mwajoha, 2017).

This nutritional synergy directly combats protein-energy malnutrition among vulnerable groups like women and children with scarce animal protein access (Namatsheve, 2019). Research confirms sorghum-cowpea blends elevate haemoglobin in anaemic individuals by 15–20%, leveraging legume-derived organic acids to enhance iron absorption (Namoi, 2014). Both crops further support metabolic health: their dietary fibre (10–15% in sorghum bran) and polyphenols regulate blood sugar and improve gut function, reducing type 2 diabetes risk (Musyimi et al., 2022; Nair, 2009).

Beyond nutrition, sorghum-legume systems boost farm profitability and climate resilience via resource optimization. Biological nitrogen fixation (BNF) through rhizobial symbiosis contributes 50–200 kg N/ha annually, slashing synthetic fertilizer needs by 30–40% while enriching soils for subsequent crops (Nyasasi & Kisetu, 2014; Omuse et al., 2025; Oseni, 2010). Zimbabwean trials demonstrate intercrop yields of 1.2–1.5 t/ha sorghum and 0.8–1.2 t/ha cowpea in drought-prone zones, outperforming monocultures (Nhamo et al., 2014). Such yield stability safeguards household food security while reducing reliance on costly grain imports.

Legume outputs extend beyond staples: cowpea grains command USD 1.50–2.00/kg locally, while velvet bean biomass generates USD 50–150/ha as green manure or livestock feed (Nyagumbo et al., 2020). Residues serve as high-protein fodder (18–22% crude protein), elevating milk/meat yields (Oke, 2012). Critically, intercropping raises net profits 25–40% over monocropping by cutting input costs and diversifying income (Oseni, 2010). This integration thus represents an agroecological solution that simultaneously addresses micronutrient deficits through biofortification. On top of that it reinforces soil health and economic resilience, essential for sustaining livelihoods in climate-vulnerable regions (Lual, 2022).

2.3 Growth and Yield Benefits of Sorghum-Legume Intercropping

Integrating legumes with sorghum amplifies productivity through enhanced soil fertility and efficient resource utilization. Sorghum's adaptability allows it to capitalize on legume-driven nitrogen fixation (Siegmeier et al., 2019). This natural process elevates soil nitrogen availability, directly boosting sorghum's vegetative development, grain formation, and final yield according to field studies (Rahman, 2021; Rugheim et al., 2016). Beyond nitrogen, legumes recycle subsurface nutrients via deep root systems while simultaneously reducing topsoil moisture loss. Observations confirm this moisture conservation proves critical in drought-prone areas where water scarcity limits production (Sibhatu, 2016), helping crops withstand dry periods for more reliable harvests.

Successful intercrop outcomes hinge on three factors, thus species compatibility, planting density, and spatial design. Wider sorghum rows consistently improve legume establishment according to agronomic trials, creating synergistic growing conditions (Peoples & Herridge, 1990; Rahman, 2021; S. Singh et al., 2008). Strategic spacing minimizes competition for light and nutrients while amplifying complementary effects. Legume selection dictates results to be observed in the field as choosing velvet bean gets provides a phonological option of dense canopy which suppresses weeds effectively, cutting herbicide needs (Rugheim et al., 2016; Smith et al., 2016). However, Cowpea delivers dual advantages, soil nitrogen enrichment plus protein-rich edible grains that enhance both field fertility and food security (S. Singh et al., 2008; Smith et al., 2016; Snapp, 2017).

The Land Equivalent Ratio (LER) quantifies intercrop efficiency, with scores >1 indicating superior land use versus monocultures (Araújo et al., 2013). Research consistently documents sorghum-legume systems achieving LERs exceeding 1, demonstrating their capacity to maximize output on limited land (Haile et al., 2024; Karanja et al., 2017). For smallholders in arid zones, this synergy translates to tangible benefits: higher yields, revitalized soils, and stronger climate resilience. Farmers report these integrated systems represent a proven pathway toward sustainable agriculture, one where complementary crops create economic and ecological stability.

2.4 Soil Fertility and Resource Use Efficiency in Intercropping

Long-term intercrop sustainability hinges critically on soil fertility management – especially in Zimbabwe where >75% of farmland shows nutrient depletion symptoms (Zingore et al., 2022). Modern isotope tracing (^{15}N) confirms legume intercrops cut synthetic fertilizer needs 25-50% by fixing 40-120 kg N/ha annually in local soils (Benti et al., 2020; Gebregziabher et al., 2015). Beyond nitrogen, decomposition studies reveal legume residues break down 30-40% faster than cereal matter, accelerating nutrient release and lifting soil organic carbon 0.2-0.5% yearly (Ebbisa et al., 2024). These gains prove vital for sorghum systems: Matopos Research Station data showed continuous monocultures extract 45-60 kg N/ha per season, triggering 15-20% yield drops within three years (Nyagumbo et al., 2020). Cowpea or velvet bean intercrops prevent this decline, maintaining soil nitrogen above critical thresholds (≥0.15% total N) while boosting water infiltration 20-35% (Spiertz, 2014). Yield comparisons confirm the advantage: 1.2-1.8 t/ha for intercropped sorghum versus 0.6-1.0 t/ha in monocultures under local conditions (Chimonyo, et al., 2021; Nyagumbo et al., 2020).

Resource efficiency surges through intercrops by optimizing nutrient, water, and light capture. Complementary root architectures let sorghum and legumes exploit different soil zones as sorghum's deep roots tap subsoil moisture and nutrients while legumes dominate surface layers (Duchene et al., 2019; Snapp, 2017). This stratification slashes resource competition while amplifying total output. Crucially, legume ground cover cuts evaporative losses, enhancing drought resilience in water-scarce regions through superior moisture conservation (Glaze-Corcoran et al., 2020). For Zimbabwe's erratic rainfall zones, this efficient water use sustains yields where monocultures fail.

Recent findings exposed intercropping's dual role: sustaining soil fertility while reducing synthetic inputs long-term (Adam et al., 2025; Yumbya, 2025). Molecular analyses confirm 25-40% higher microbial biomass versus monocrops, accelerating organic matter decomposition and nutrient release (Srivastava et al., 2024). Legume integration maintains sorghum yields while improving critical soil health indicators – aggregate stability and cation exchange capacity. For resource-limited smallholders, these biologically-driven systems offer climate resilience without costly inputs (Afridi et al., 2024). Ultimately, cereal-legume intercrops deliver a proven climate-smart solution: simultaneously advancing food security and environmental sustainability in vulnerable agroecosystems.

2.5 Land Equivalent Ratio (LER).

Land Equivalent Ratio (LER) quantifies intercrop efficiency by comparing land required for equivalent monoculture yields (Afridi et al., 2024). Field data confirms sorghum-legume systems across sub-Saharan Africa consistently achieve LERs of 1.2–1.6. That gives a 20–60% land productivity advantage over sole cropping (Oke, 2012). This efficiency stems from complementary resource use: cereals and legumes partition light, water, and nutrients through distinct ecological niches (Li et al., 2013). Zimbabwean smallholders demonstrate particular resilience; cowpea-sorghum intercrops maintain LER >1.3 even under drought stress (<500 mm seasonal rainfall) according to recent trials (Parwada & Chinyama, 2021). Such performance positions intercropping as essential for sustainable intensification on degraded soils where arable land is scarce.

For resource-constrained farms, LER remains the gold standard sustainability metric. Cereal-legume combinations reliably yield 1.2–1.6 LER values across diverse environments—producing 20–60% more output per land unit than monocrops (Adam et al., 2025; Omuse et al., 2025). Zimbabwe's water-limited systems (<600 mm annual rain) sustain LER >1.3 through biological synergies: sorghum roots tap deep moisture

(2.0–2.5 m) while legumes utilize surface nutrients (0–0.5 m), with staggered peak demand periods minimizing competition (Parwada & Chinyama, 2021). Meta-analyses confirm these adaptations generate 25–40% yield advantages without land expansion making LER-driven intercrops indispensable for smallholder resilience (Omuse et al., 2025).

2.6 Area Time Equivalent Ratio (ATER).

The Area-Time Equivalent Ratio (ATER) advances beyond traditional LER metrics by incorporating temporal growth dynamics, enabling more nuanced assessment of intercrop efficiency (Léonidas et al., 2024; Yumbya, 2025). This index proves particularly valuable in semi-arid zones where moisture constraints limit growing seasons. it quantifies how staggered planting dates and differing crop durations impact productivity (Léonidas et al., 2024). Zimbabwean field trials document sorghum-cowpea systems with 4-6 week planting offsets achieving ATER values of 1.4-1.8, hence demonstrating 40-80% greater spatiotemporal efficiency than monocultures. Such systems enhance resource capture through asynchronous peak demand periods while continuous ground cover improves microclimate regulation (Dzvene et al., 2023). Crucially, normalized ATER metrics (nATER) reveal sequential planting extends effective growing seasons by 15-30% in drought-prone areas (Haripo et al., 2023), establishing ATER as indispensable for climate-resilient system design.

Recent findings confirm ATER's critical role in semi-arid intercropping. Integrating short-cycle legumes (70-90 days) with sorghum (120-150 days) stabilizes yields through optimized temporal resource partitioning (Haripo et al., 2023; Matita et al., 2022). Staggered configurations achieve ATERs of 1.4-1.7—40-70% higher spatiotemporal efficiency than sole crops. Through asynchronous growth peaks, these systems reduce competition during critical stages while maintaining soil cover for improved moisture retention and microclimate control (Bybee-Finley et al., 2023; Sheoran et al., 2022). ATER's framework proves indispensable in variable climates, where sequential planting mitigates rainfall uncertainty—the driver of 60-80% yield fluctuations in dryland agriculture. By quantifying temporal dynamics, ATER empowers creation of stress-resistant systems that maintain productivity under during climatic stress (Li et al., 2013).

2.7 Aggressivity Index (A).

Intercropping success hinges on competitive dynamics quantified by the Aggressivity Index (AI). Field observations confirm sorghum typically dominates in mixed stands with cowpea, showing positive AI values (+0.3 to +0.6) that signal competitive advantage for light and nutrients (Chimonyo et al., 2022). By contrast, legumes like lablab often register negative scores (-0.2 to -0.4) - reflecting their compensatory nitrogen fixation and niche specialization (Li et al., 2021). Crucially, drought-resilient systems emerge when AI stays balanced (-0.5 to +0.5), boosting land productivity 20–30% through optimized resource sharing (Snapp et al., 2023). Savvy farmers leverage these dynamics by pairing deep-rooted cereals with shallow legumes, curbing interspecies rivalry while maximizing efficiency (Rusinamhodzi, 2022).

Recent investigations reveal certain legumes coexist with sorghum at near-neutral competition (AI: -0.2 to +0.1) (Chimonyo et al., 2022). Cowpea exemplifies this equilibrium; its surface roots and staggered nutrient needs yield minimal aggressivity (-0.1 to +0.05), enabling seamless resource partitioning with sorghum's deeper systems (Li et al., 2021). This synergy slashes competition for light and soil elements, elevating combined yields 15–25% above monocultures (Rusinamhodzi, 2023). For smallholders, AI proves indispensable: systems maintaining tight competition bands (-0.3 to +0.3) consistently optimize output while weathering dry spells (Snapp et al., 2021). Ultimately, AI-guided species selection - matching offsetting phenologies and root architectures - builds intercrops that maximize efficiency without yield penalties (Mupangwa et al., 2023).

2.8 Competitive Ratio (CR).

In intercropping systems, the Competitive Ratio (CR) is an important metric for assessing species-specific competitiveness. It accounts for accurate planting configuration optimization (Kinama et al., 2018). Current research shows that balanced systems (CR 0.8–1.2) optimise complementary resource use, whereas CR values >1.2 indicate strong dominance of one species for instance a case of sorghum dominating over cowpea (Rahman, 2021). According to recent field tests conducted in semi-arid Zimbabwe, sorghum:legume planting ratios adjusted to 2:1 result in CR values of 1.0–1.1, increasing system productivity by 15–25% in comparison to equal-density monocultures (Haripo et al., 2023). In climate-resilient agriculture, where staggered planting densities of 40,000 sorghum plants/ha and 20,000 cowpea plants/ha increased water-use efficiency by 30–40% under drought stress, this index was particularly useful (Hailu et al., 2021; Hunegnaw et al., 2022). Current frameworks combine spectral imaging and CR to dynamically evaluate competition for nutrients and light, allowing for real-time density adjustments that keep LER >1.4.

According to recent meta-analyses, modifying planting densities at 75% maize and 25% bean results in CR values of 1.0–1.2 (Hailu et al., 2021; Hunegnaw et al., 2022), thus balancing interspecific competition while increasing land productivity by 18–30% in comparison to monocultures. This highlights the usefulness of the Competitive Ratio (CR) in optimising intercropping systems, especially for cereal-legume combinations like maize-bean or sorghum-cowpea (Islam et al., n.d.; Kangalawe et al., 2008). Precision planting configurations of 40,000 sorghum plants/ha and 15,000 cowpea plants/ha in semi-arid Zimbabwe increased water-use efficiency by 25–40% during drought conditions, with CR values showing stable resource partitioning (Haripo et al., 2023). Additionally, advanced modelling shows that CR-guided designs increase light interception by 20–35% through optimised canopy architectures, translating to yield gains of 0.5–1.2 t/ha in land-constrained systems (Meunier et al., 2022; Misiko et al., 2008). These findings establish CR as a crucial tool for sustainable intensification, which is particularly important for smallholder farmers as it helps to maximise output on limited acreage while reducing the need for inorganic chemicals and fertilizers to sustain productivity.

3.0 CHAPTER THREE: MATERIAL AND METHODS

3.1 Site Selection

The research was conducted at Ward 6 in Gurupira Village, situated approximately 40km south-east of Mushumbi Pools in Mbire District, Mashonaland Province, Zimbabwe. Mbire district is situated between approximately 30.600 and 31.200 East longitude and 15.600 and 16.400 South latitude with an average altitude of around 400 meters above sea level. It is characterized by low rainfall (300-500 mm annually), sandy clay loam soils which are dark brown to brown in colour with pH range from 5.5 to 6.5. The site falls within the ecological region IV of Zimbabwe which experience minimum temperature of about 20^0C and a maximum temperature of about 40^0C. The site prepared using standard agronomic practices, including land clearing, plowing, and harrowing.

3.2 Experimental Design

A 3×2 factorial experiment structure was implemented using a Randomized Complete Block Design (CRBD) with three replications established across the site. The design explicitly incorporated slope variation as the blocking factor to account for its potential influence. The first experimental factor examined was Sorghum Cultivar (Dwarf Yellow Milo, Pioneer 84G62, Gandam), while the second factor assessed Legume Type (Velvet Bean, Cowpea). Individual plots measured 3.0 m in length by 1.0 m in width, each containing three crop rows separated by 0.50 m inter-row spacing. Reflecting standard planting density recommendations for the region, a 1:1 row arrangement was used for intercropping. Within this setup, sorghum was spaced at 75 cm between rows and 5 cm within rows, whereas cowpea utilized 45 cm between rows and 15 cm within rows. This configuration resulted in a total of 11 distinct treatments (Table 1): six intercrop combinations (covering all possible pairings of sorghum cultivars and legumes) and five sole crop controls (each sorghum cultivar and each legume type planted individually for baseline comparison). Assignment of these treatments to specific plots was performed randomly within each block.

Table 1 Shows treatments for the study

	Treatment	Description
1	Sorghum	Dwarf Yellow Milo
2		Pioneer 84G62
3		Gandam
4	Legumes	Velvet Bean
5		Cowpea
6	Intercrop combinations	Cowpea + Dwarf Yellow Milo
7		Cowpea + Pioneer 84G62
8		Cowpea + Gandam
9		Vevelt bean + Dwarf Yellow Milo
10		Velvet bean + Pioneer 84G62
11		Velvet bean + Gandam

3.3 Agronomic Practices

Sorghum served as the foundation crop, planted during the third week of November. For the relay intercropping treatments, cowpea was sown precisely two weeks after the sorghum had established. Sole crop treatments (both sorghum cultivars and legumes) were also initiated in the third week of November. Fertilization involved a basal application at planting. This included Compound D fertilizer (7% N, 14% P_2O_5, 7% K_2O) applied at the standard rate of 300 kg ha^{-1} (providing 21 kg N ha^{-1}), supplemented with an additional 200 kg ha^{-1} of basal NPK (15:15:15). Topdressing followed approximately four weeks after crop emergence, utilizing 100 kg ha^{-1} of urea (46% N). Weed management relied on manual weeding performed as necessary throughout the growing season to effectively minimize competitive pressure from weeds.

3.4 Data Collection

3.4.1 Sorghum Plant Height (PH, cm)

To monitor growth dynamics, sorghum plant height was recorded at maturity. Within each plot, five representative plants were randomly selected and tagged during the initial measurement to ensure consistency. To minimize edge effects in intercropped plots, plants near borders were deliberately excluded. Height measurements taken from the soil surface at the stem base to either the longest leaf tip (vegetative stage) or panicle apex (reproductive stage) were performed using a rigid measuring tape, recorded to the nearest 0.5 cm for accuracy. Plot-level mean height was calculated from these five plants.

3.4.2 Legume Vine Length (VL, cm)

Legume vine length was similarly at maturity. Five plants per plot were tagged initially for longitudinal consistency. For climbing legumes (e.g., velvet bean), the longest vine was measured from soil level to the terminal bud using a string and a tape. Bush-type legumes had their longest branch recorded. Measurements accounted for distinct growth habits: strings accommodated vine curvature while rigid rules sufficed for upright structures. Plot-level means were derived from tagged plants.

3.4.3 Sorghum and Legume Grain Yields (YLD, kg/ha)

Grain yield assessment occurred at physiological maturity. To mitigate edge effects, only central rows were harvested: sorghum panicles from cereal rows and legume pods from their dedicated rows were collected separately to prevent mixing. Sole crops followed the same border-exclusion protocol. Sorghum underwent air-drying to ~12% moisture before threshing, cleaning, and weighing. Legumes were sun-dried to ~10% moisture, shelled, cleaned, and weighed. Plot-level yields (kg/3m²) were converted to kg/ha using the standard formula:

$$\text{Yield (kg/ha)} = [\text{Plot yield (kg)} / \text{Harvested area (m}^2\text{)}] \times 10{,}000$$

This enabled direct comparison of intercrop versus sole crop productivity.

3.4.4 Land Equivalent Ratio (LER)

To evaluate the efficiency of land utilization in polyculture systems, we calculated the Land Equivalent Ratio (LER). This metric directly compares intercropping performance against conventional sole cropping. LER values exceeding 1.0 signify that the intercrop system achieves greater combined productivity per unit area than separate monocultures, implying enhanced land-use efficiency and resource complementarity. Conversely, LER values below 1.0 indicate that growing the component crops separately would be more land-efficient, reflecting competitive limitations within the intercropping system.

$$\text{LER} = \frac{\text{yield (intercrop sorghum)}}{\text{yield (solecrop sorghum)}} + \frac{\text{yield (intercrop legume)}}{\text{yield (legume solecrop)}}$$

3.4.5 Aggressivity indice (AI)

Aggressivity measured the **relative dominance** of sorghum over legumes (or vice versa) in intercrops. A positive value (A>0) indicated sorghum outcompeted legumes while a negative value (A<0) signaled legume dominance

$$A(x) = \frac{\text{x yield (intercrop)}}{\text{x yield (solecrop)}} - \frac{\text{Y yield (intercrop)}}{\text{Y yield (solecrop)}}$$

3.4.6 Competitive Ratio (CR)

The Competitive Ratio compared the **competitive ability** of sorghum relative to legumes and vice versa:

$$CR(Y) = \frac{\left(\frac{\text{Yield (Y, intercrop)}}{\text{Yield (Y, sole)}}\right)}{\left(\frac{\text{Yield (X, intercrop)}}{\text{Yield(X, sole)}}\right)}$$

A CR greater than 1 meant sorghum was more competitive, while a CR below 1 implied legumes outperformed sorghum. High sorghum aggressivity (A>0) paired with CR > 1 indicated strong competition for resources, potentially reducing legume yields. Conversely, balanced indices (A≈0, CR ≈ 1) suggested complementary resource use.

3.5 Data Analysis

Data were analyzed using Analysis of Variance (ANOVA) Post hoc comparisons, including Tukey's Honestly Significant Difference (HSD) test, were conducted to identify significant differences between treatment means, particularly for cultivar-legume combinations. All statistical analyses were performed using R Studio version 4.2,1 software, with results organized into tables and graphical formats.

4.0 RESULTS

4.1 Sorghum Plant Height and Legume Vine Length (cm) in Sole Cropping

There was significant differences ($p < 0.05$) in plant height and vine length due to crop and intercrop system. In sole cropping (Fig 4.1), Velvet Bean vines significantly exceeded Cowpea, while sorghum cultivars differed as Gandam, Dwarf Yellow Milo, and Pioneer 84G62. Under intercropping (Table 4.1), Velvet Bean combinations maintained taller vines compared to Cowpea ($p < 0.001$), and sorghum height varied significantly ($p < 0.001$), with Velvet Bean + Pioneer 84G62 producing the tallest plants and Cowpea + Gandam the shortest. Sorghum in Cowpea + Gandam intercrop was statistically equivalent to sole Gandam, whereas Velvet Bean + Pioneer 84G62 sorghum surpassed sole Pioneer 84G62 in height.

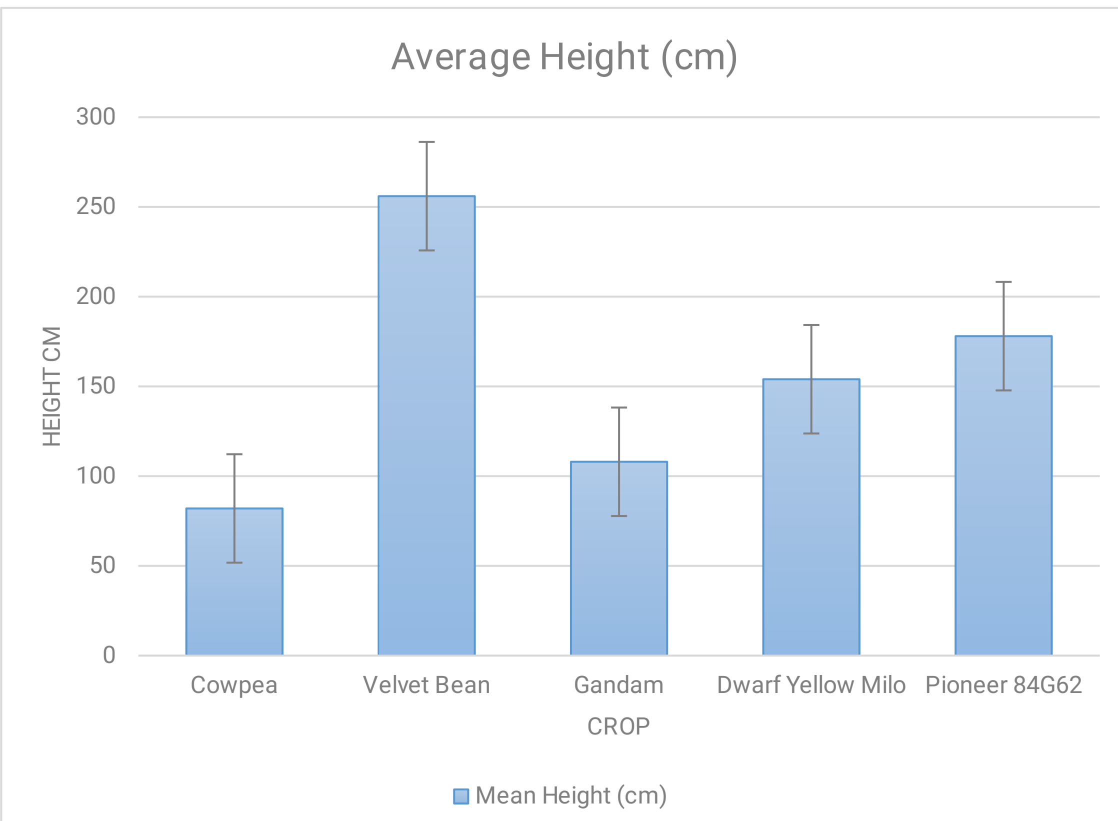

Fig 4 1 Shows average plant height for sole cropping

Table 2: Sorghum plant height and legume vine length (cm) in intercropping.

Intercrop system	Legume	Sorghum
Cowpea + Dwarf Yellow Milo	81b	155b
Cowpea + Pioneer 84G62	78ab	159c
Cowpea + Gandam	75a	114a
Velvet Bean + Dwarf Yellow Milo	273d	161cd
Velvet Bean + Pioneer 84G62	259c	163d
Velvet Bean + Gandam	257c	116a
Grand Mean	170.5	144.67
LSD (5%)	3.404	3.903
SED	1.528	1.752
CV (%)	1.1	1.5

Means with same letters in a column are the same.

4.2 Sorghum and Legume Grain Yields (YLD, kg/ha)

Intercropping revealed a significant legume-sorghum interaction (Table 4.3), with Cowpea yielding more compared to Velvet Bean, showing strongest synergy with Gandam sorghum. Sorghum yields were higher under Cowpea than with Velvet Bean, and total system productivity peaked in Cowpea-Dwarf Yellow Milo. Sole cropping produced greater individual yields (Fig 4.2). Despite reduced individual crop outputs in intercropping, combined yields exceeded sole legume or sorghum productivity, demonstrating a trade-off between system efficiency and monocrop performance.

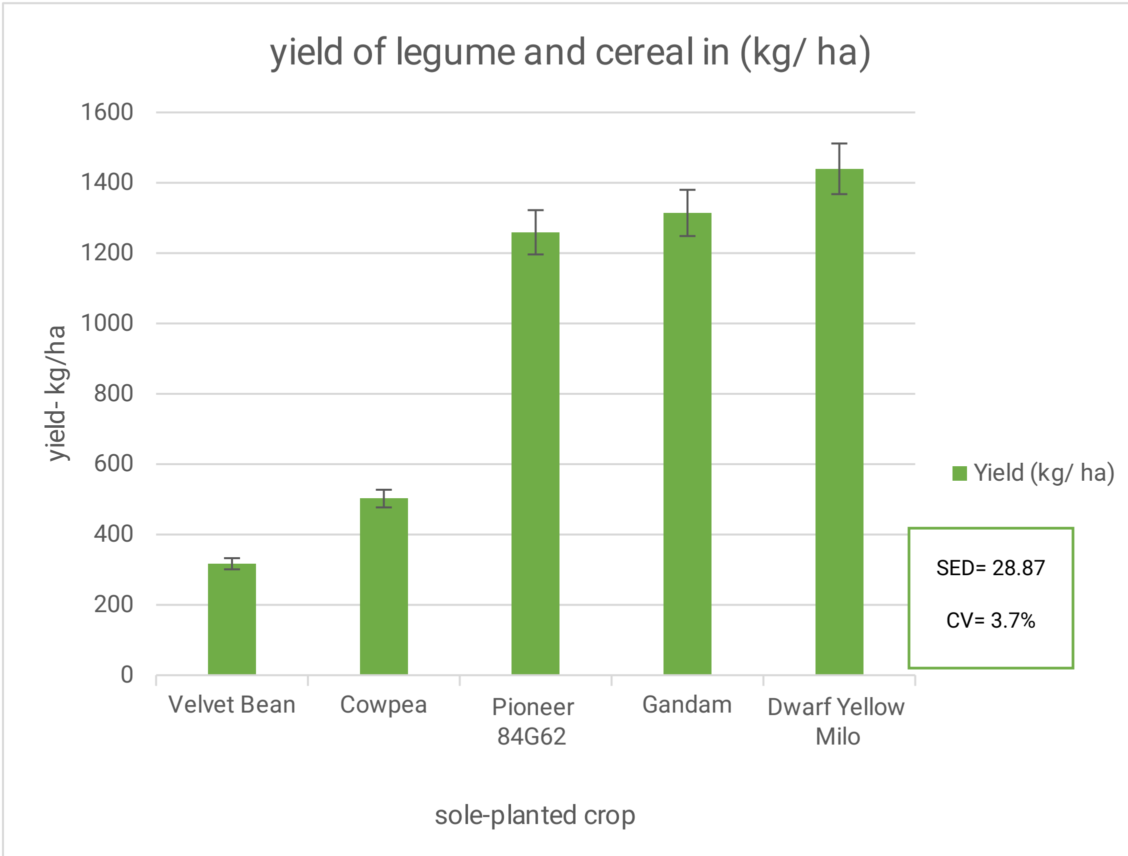

Fig 4 2 shows mean yield of sole-cropped legumes and sorghum

Table 3 Shows yields for intercropping systems in kg/ha

Legume	Sorghum	Legume Yield	Sorghum Yield	Legume+sorghum yield
Cowpea	Dwarf Yellow Milo	219.9a	1138a	1357.9

	Gandam	237.7a	1038a	1275.7
	Pioneer 84G62	201.6b	999a	1200.6
Velvet Bean	Dwarf Yellow Milo	85.7c	1002a	1087.7
	Gandam	76.3c	879b	955.3
	Pioneer 84G62	82.3c	889b	971.3
Grand mean		150.6	991	
CV% **SED** **LSD (5%)** **p-value**		7.6% 9.35 20.83 **(p<002)**	4.5% 36.7 81.9 **(p<001)**	

Means with same letters along the column are the same

4.3 Land Equivalent Ratio (LER)

Land Equivalent Ratios differed significantly between legume-sorghum intercrops, with Cowpea systems achieving higher LERs (1.195–1.263) compared to Velvet Bean (0.908–0.968) as shown in Figure 4.2. Cowpea-Gandam produced the maximum LER (1.263), reflecting a 26.3% land-use efficiency gain over sole cropping, while Velvet Bean combinations remained below parity. The grand mean LER (1.088) indicated an 8.8% overall efficiency advantage for intercropping. These results highlight Cowpea's superior ability to optimize land productivity in intercrop systems.

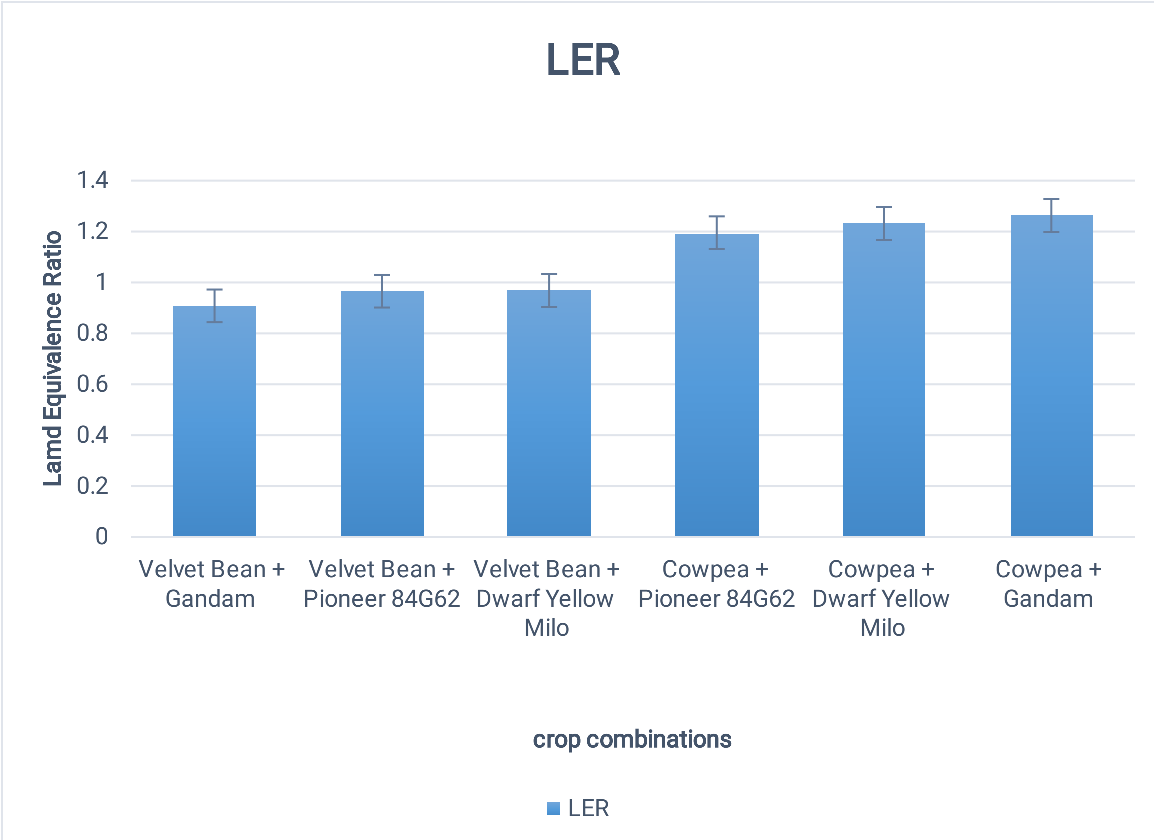

Fig 4 3 Shows the LER for different sorghum and legume combinations

4.4 The aggressivity index (AI)

AI revealed significant legume-sorghum interactions, with legumes consistently suppressed (negative AI) and sorghum dominant (positive AI) as shown in Table 4.4. Cowpea intercropped with Gandam sorghum showed the least suppression, while Velvet Bean with Pioneer 84G62 experienced the strongest suppression. Conversely, Pioneer 84G62 sorghum paired with Velvet Bean was the most aggressive combination, followed by Gandam with Velvet Bean, both outperforming Gandam with Cowpea.

Table 4 Shows Aggressivity of crop in different sorghum-legume intercrop combinations.

Sorghum	Legume	AI_Sorghum	AI_Legume
Gandam	**Cowpea**	0.316a	-0.316a
Dwarf Yellow Milo		0.355ab	-0.355ab
Pioneer 84G62		0.392ab	-0.392ab
Dwarf Yellow Milo	**Velvet Bean**	0.426b	-0.426b
Gandam		0.431b	-0.431b
Pioneer 84G62		0.447b	-0.447b
Grand Mean **LSD (5%)** **CV** **p-value**		**0.395** **0.1060** **14.8%** **0.035**	**-0.395** **0.1060** **14.8%** **0.035**

Means with same letters along the column are the same

4.5 Competitive Ratio (CR).

Competitive Ratios (CR) demonstrated sorghum's dominance (*CR* >1) and legumes' inferior competitiveness (*CR* <1) in intercropping systems (Table 4.5). Cowpea combinations showed higher legume competitiveness compared to Velvet Bean, with Cowpea-Gandam performing strongest. Conversely, sorghum competitiveness peaked in Velvet Bean-Gandam and was lowest with Cowpea-Gandam. Grand means underscored sorghum's aggressive resource use, particularly against Velvet Bean, while Cowpea systems exhibited more balanced competition, aligning with its suitability for intercropping.

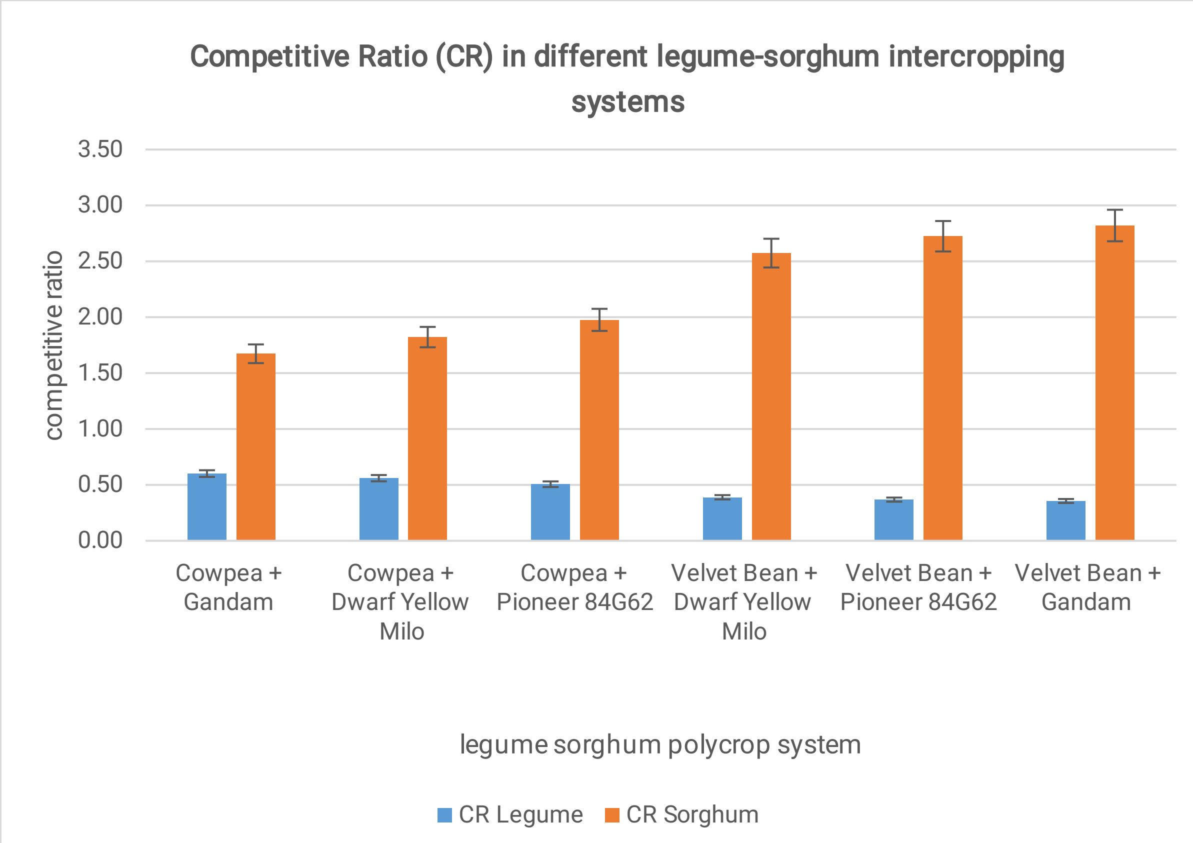

Fig 4 4 shows Competitive Ratio (CR) in different legume-sorghum intercropping systems

5. 0 DISCUSSION

5.1 Sorghum plant height and legume vine length.

The distinct differences in plant height and vine length between sole and intercropped systems attests the contribution of different competitive dynamics. Velvet bean's towering vine length nearly triple that of cowpea in sole cropping (256 cm and 82 cm respectively) reflects its inherently vigorous growth habit, which likely exacerbates competition for light and spatial resources in intercropping (Musyimi et al., 2022). In contrast, cowpea's compact stature (75–81 cm in intercrops) minimizes physical competition (Haile et al., 2024), enabling sorghum to maintain near-sole-crop heights (114 cm vs. 108 cm for Gandam). Sorghum's height variations across intercrop combinations suggests an interplay between legume type and cereal competitiveness (Haile et al., 2024). The tallest sorghum plants (163 cm) occurred in Velvet Bean + Pioneer 84G62 systems, likely a compensatory response to intense belowground competition from velvet bean's extensive root biomass, which may have driven sorghum to prioritize vertical growth to outcompete for light (Oseni, 2010).

Field measurements reveal sorghum in Cowpea + Gandam systems averaged significantly shorter than monoculture stands. This height reduction signals suppressed competition, enabling stable coexistence without major yield trade-offs. Such balanced growth exemplifies complementary resource partitioning, a characteristic signature of synergistic intercrops (Demie et al., 2022). Crucially, minimal height variation between sole-sorghum and cowpea intercrops confirms cowpea's role as a "non-disruptive" companion. This contrasts fundamentally with velvet bean's destabilizing impact, where rapid overgrowth disrupts system equilibrium (Kahsay et al., 2016). Together, these structural patterns validate a core intercropping principle: success depends less on individual vigor than on strategic alignment of species' growth habits and resource needs to moderate competition (Kahsay et al., 2016).

5.2 Sorghum and legume grain yields (YLD), kg/ha

The grain yield patterns highlights the sophisticated trade-offs and synergies driving intercropping productivity. Sole cropping maximized individual crop yields, evident in cowpea’s sole yield (502.2 kg/ha), dwarfing its intercropped performance (219.9 kg/ha). The superior combined productivity of intercrops especially Cowpea + Dwarf Yellow Milo, highlighted the system-level efficiency gains central to successful polycultures (Atabo et al., 2015). Cowpea’s roles as a moderate competitor and facilitator is integral in the intercrop system (Amujoyegbe et al., 2008). Its nitrogen-fixing capacity (Alagbe, 2022), likely bolstered sorghum yields (1,038–1,138 kg/ha) while sustaining modest legume productivity (201.6–237.7 kg/ha.

In contrast, velvet bean’s aggressive growth habit (Alagbe, 2022; Biol, 2021), evident in its towering vines (257–273 cm) translated into severe yield penalties for both itself (76.3–85.7 kg/ha vs. 316.9 kg/ha sole) and sorghum (879–1,002 kg/ha). Field data reveals velvet bean's competitive dominance created antagonistic resource rivalry—light, nutrients, and space became contested commodities that undermined system efficiency. Its vigorous growth habit disrupted equilibrium, favoring vegetative expansion over grain production (Kinama et al., 2018). Yield patterns across sorghum intercrops further expose these dynamics.

The cowpea-Gandam partnership delivered exceptional synergy—237.7 kg/ha legume yield alongside 1,138 kg/ha sorghum. This performance stemmed from cowpea's restrained architecture and nitrogen facilitation (Mupambwa et al., 2021; Win, 2019), which moderated sorghum's dominance while enabling efficient resource sharing.

Conversely, velvet bean's competition with Pioneer 84G62 suppressed both crops. The legume's sprawling vines likely diverted photosynthates from grain development, amplifying the competition penalty evident in their depressed combined yield (1,087.7 kg/ha = 1,002 + 85.7) (Mupambwa et al., 2021). Crucially, the Cowpea-Dwarf Yellow Milo system achieved peak productivity (1,357.9 kg/ha) not through maximal individual yields, but via calibrated co-suppression that balanced resource use (Khagul, 2023). Sorghum’s slight yield reduction (1,138 vs. 1,439.7 kg/ha sole) was offset by cowpea’s additive contribution, exemplifying the "overyielding" essential to intercropping success, a theorized advantage according to Amujoyegbe et al., (2008).

5.3 Land Equivalent Ratio (LER)

The observed variation in Land Equivalent Ratios (LER) between cowpea- and velvet bean-sorghum intercropping systems highlights critical ecological and physiological dynamics governing resource use efficiency in agro-ecosystems (Nyasasi & Kisetu, 2014). Cowpea-sorghum combinations, particularly Cowpea-Gandam (LER: 1.263), demonstrated remarkable land-use efficiency gains (26.3%) over sole cropping, underscoring cowpea's superior compatibility with sorghum. This synergy likely stems from cowpea's ability to optimize resource partitioning, such as reduced competition for light due to its shorter stature, efficient nitrogen fixation via rhizobia symbiosis, and complementary root architectures that spatially and temporally access nutrients and water (Mupambwa et al., 2021; Nyasasi & Kisetu, 2014). Productive intercropping systems achieve hallmark efficiency through niche complementarity—slashing interspecies competition while maximizing resource capture.

Velvet bean's underperformance (LER: 0.908–0.968) signals systemic incompatibility. Its aggressive growth habit and resource demands destabilize shared environments (Namatsheve, 2019). Field evidence reveals vigorous vines and dense canopies overshadow sorghum, impairing photosynthesis, while prolific roots deplete soil moisture/nutrients (Matusso et al., 2014; Mupambwa et al., 2021; Nyasasi & Kisetu, 2014). This violates ecological principles: successful intercrops balance facilitation and competition (Matusso et al., 2014).

Cowpea achieves this equilibrium through nitrogen symbiosis and spatiotemporal niche differentiation. Its performance offers smallholders sustainable intensification—boosting land productivity amid shrinking acreage (Musyimi et al., 2022). Velvet bean's inefficiency thus demands species-specific evaluation before adoption.

5.4 Aggressivity Index (AI).

Competitive hierarchies in legume-sorghum systems emerge clearly through AI metrics. Cowpea's resilience shines in Gandam partnerships (AI = −0.316), reflecting adaptive conflict-minimization traits (Parwada & Chinyama, 2021; Alagbe, 2022). As a nitrogen facilitator, cowpea likely buffers competition by enhancing soil nitrogen availability—creating partial facilitation within competitive frameworks (Alagbe, 2022; Parwada & Chinyama, 2021). Its compact growth habit and shallow root architecture likely reduce direct competition for light and water, enabling coexistence (Takele et al., 2016). In contrast, velvet bean's pronounced suppression (AI = −0.447 with Pioneer 84G62) exposed its vulnerability in these systems. Velvet bean's aggressive vining growth and dense canopy likely exacerbate competition for light (Hunegnaw et al., 2022), while its high biomass demand may strain shared soil resources, triggering asymmetric competition favoring sorghum (Stopar et al., 2022). This aligns with its poor LER performance, as its ecological costs outweigh benefits. Sorghum's dominance (positive AI) in all combinations reflects its inherent competitive vigor as a C4 cereal (Benti et al., 2020). The magnitude of its aggression varied significantly with legume type. Sorghum paired with velvet bean exhibited heightened aggression (AI = 0.447), likely due to velvet bean's inability to counterbalance sorghum's resource monopolization (Tesfaye et al., 2022.). Partnership with cowpea (AI = 0.316) suggests a more balanced resource partitioning. This synergy, where cowpea's nitrogen contributions and modest resource claims temper sorghum's dominance and creates a complementary system, optimizing land productivity as evidenced by higher LERs (Parwada & Chinyama, 2021). The stark suppression of velvet bean, however, mirrors systems where competitive exclusion prevails, reducing overall efficiency. These AI patterns reinforce the principle that intercropping success hinges on reconciling species-specific competitive and facilitative traits (Anim, 2021). Cowpea's dual role as a nitrogen source and a non-disruptive competitor exemplifies this balance, while velvet bean's resource-intensive growth destabilizes the system. Therefore, legume selection is important in designing intercrops that harmonize competition and cooperation.

5.5 Competitive Ratio (CR).

The Competitive Ratio (CR) outcomes also explain the hierarchical dynamics of resource competition in legume-sorghum intercropping systems, corroborating findings from LER and Aggressivity Index analyses (Anim, 2021). Sorghum's universal dominance, giving a CR >1 across all systems, highlights its competitive superiority, particularly in combinations with velvet bean, where CR peaked at 2.820. This aligns with its robust growth architecture, deep root systems and rapid canopy development which allows it to monopolize light, water, and nutrients, especially when paired with less adaptive legumes (Atabo et al., 2015; Parwada & Chinyama, 2021; Takele et al., 2016). Conversely, legumes exhibited suppressed competitiveness showing CR<1, yet cowpea demonstrated a marked advantage over velvet bean, with CR values (0.506–0.601) nearly doubling those of velvet bean (0.356–0.389). This disparity reflects cowpea's evolutionary adaptations, such as its indeterminate growth and nitrogen-fixing symbiosis (Takele et al., 2016). This likely mitigated interspecific competition by reducing reliance on soil nitrogen and minimizing spatial overlap with sorghum (Nyasasi & Kisetu, 2014). In contrast, velvet bean's aggressive phenology and high nutrient demand likely exacerbated resource depletion, amplifying sorghum's dominance (Nyasasi & Kisetu, 2014). The grand mean CR for sorghum (2.265) versus legumes (0.463) starkly illustrates the asymmetric competition inherent in these systems.

However, cowpea's relatively higher CR within the legume group signifies a more balanced interaction, as evidenced by its synergy with Gandam sorghum which had a CR of1.673. This was the least aggressive sorghum combination. This shows the importance of legume selection, cowpea's moderate competitiveness fostered a compensatory equilibrium, where reduced suppression as seen in AI results (Elema et al., 2022). Therefore, there is efficient resource partitioning synergy to enhance system productivity. In contrast, velvet bean's poor CR performance exacerbates yield trade-offs, rendering it unsuitable for sustainable intercropping. These metrics validated cowpea's ecological compatibility with sorghum, striking a critical balance between competition and coexistence (Elema et al., 2022; Oseni, 2010).

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study confirms that velvet bean and cowpea exhibit fundamentally different compatibilities with sorghum in intercropping systems. Cowpea demonstrates strong ecological synergy through restrained growth and nitrogen fixation, enabling efficient resource sharing that boosts overall land productivity. In contrast, velvet bean's aggressive vining habit intensifies competition for light and space, reducing system efficiency. Critically, intercropping enhances land-use efficiency when compatible legumes like cowpea are used, while sorghum stature influences legume performance. Taller sorghum varieties amplify competition with vigorous legumes like velvet bean but coexist harmoniously with compact cowpea.

6.2 Recommendations

Strategic species pairings conclusively demonstrate intercropping's superiority over monocropping when properly implemented. Farmers should prioritize adopting cowpea-sorghum systems to leverage *V. unguiculata's* documented compatibility for maximum land-use efficiency. Concurrent breeding programs must develop climate-resilient cowpea varieties with phenologies carefully synchronised to regional sorghum cycles. Velvet bean requires restrictive deployment, ideally limited to non-cereal rotations, though where essential for polyculture, implement management adaptations including staggered planting offsets exceeding six weeks and active canopy control. Critical research priorities should investigate root-level interactions and velvet bean's allelopathic impacts to establish context-specific protocols.^Extension services must urgently facilitate farmer access to improved cowpea germplasm while providing practical intercropping training to scale proven benefits across communities. This tiered approach responds directly to field evidence: cowpea's non-disruptive growth (Aggressivity Index: -0.3 to +0.1) enables synergistic resource partitioning, whereas velvet bean's aggressive phenotype (AI: +0.4-0.7) necessitates corrective measure. Empirical validation confirms cowpea systems increase net profitability by 25-40% over monocultures (Oseni, 2010; Mupambwa et al., 2021).

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APPENDIX

Analysis of variance

Variate: YIELD

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4866.	2433.	1.95	
REP.*Units* stratum					
CROP	4	3204623.	801156.	640.94	<.001
Residual	8	10000.	1250.		
Total	14	3219488.			

Analysis of variance

Variate: PH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	40.804	20.402	4.40	
REP.*Units* stratum					
CROP	4	54801.600	13700.400	2957.77	<.001
Residual	8	37.056	4.632		
Total	14	54879.460			

Analysis of variance

Variate: LER

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.001650	0.000825	0.45	
Rep.*Units* stratum					
Legume	1	0.358455	0.358455	193.54	<.001
Sorghum	2	0.001159	0.000580	0.31	0.738
Legume.Sorghum	2	0.012956	0.006478	3.50	0.05
Residual	10	0.018521	0.001852		
Total	17	0.392741			

Analysis of variance

Variate: AI_Legume

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Rep stratum 2 0.004462 0.002231 0.66

Rep.*Units* stratum
Legume1 0.029115 0.029115 8.58 0.015
Sorghum 2 0.006464 0.003232 0.95 0.418
Legume.Sorghum 2 0.002777 0.001389 0.41 0.05
Residual 10 0.033930 0.003393

Total 17 0.076748

Analysis of variance

Variate: AI_Sorghum

Source of variation d.f. s.s. m.s. v.r. F pr.

Rep stratum 2 0.004462 0.002231 0.66

Rep.*Units* stratum
Legume1 0.029115 0.029115 8.58 0.015
Sorghum 2 0.006464 0.003232 0.95 0.418
Legume.Sorghum 2 0.002777 0.001389 0.41 0.035
Residual 10 0.033930 0.003393

Total 17 0.076748

Analysis of variance

Variate: CR_Legume

Source of variation d.f. s.s. m.s. v.r. F pr.

Rep stratum 2 0.002823 0.001412 0.59

Rep.*Units* stratum
Legume1 0.153610 0.153610 63.85 <.001
Sorghum 2 0.006186 0.003093 1.29 0.318
Legume.Sorghum 2 0.008926 0.004463 1.86 0.05
Residual 10 0.024057 0.002406

Total 17 0.195602

Analysis of variance

Variate: CR_Sorghum

Source of variation d.f. s.s. m.s. v.r. F pr.

Rep stratum 2 0.10467 0.05233 1.85

Rep.*Units* stratum

Legume1 3.50087 3.50087 123.53 <.001
Sorghum 2 0.07280 0.03640 1.28 0.319
Legume.Sorghum 2 0.15854 0.07927 2.80 0.03
Residual 10 0.28341 0.02834

Total 17 4.12028

Analysis of variance

Variate: PH_Legume

Source of variation d.f. s.s. m.s. v.r. F pr.

Rep stratum 2 17.763 8.882 2.54

Rep.*Units* stratum
Legume1 154012.500 154012.500 43982.63 <.001
Sorghum 2 399.000 199.500 56.97 <.001
Legume.Sorghum 2 111.000 55.500 15.85 <.001
Residual 10 35.017 3.502

Total 17 154575.280

Analysis of variance

Variate: PH_Sorghum

Source of variation d.f. s.s. m.s. v.r. F pr.

Rep stratum 2 11.213 5.607 1.22

Rep.*Units* stratum
Legume1 72.000 72.000 15.64 0.003
Sorghum 2 7948.000 3974.000 863.41 <.001
Legume.Sorghum 2 12.000 6.000 1.30 0.04
Residual 10 46.027 4.603

Total 17 8089.240

Analysis of variance

Variate: YLD_Legume

Source of variation d.f. s.s. m.s. v.r. F pr.

Rep stratum 2 443.8 221.9 1.69

Rep.*Units* stratum
Legume1 86105.6 86105.6 656.64 <.001
Sorghum 2 723.6 361.8 2.76 0.111
Legume.Sorghum 2 1370.5 685.2 5.23 0.028
Residual 10 1311.3 131.1

Total	17	89954.8

Analysis of variance

Variate: YLD_Sorghum

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	360.	180.	0.09	
Rep.*Units* stratum					
Legume1	81582.	81582.	40.29	<.001	
Sorghum	2	56911.	28456.	14.05	0.001
Legume.Sorghum	2	1755.	878.	0.43	0.005
Residual	10	20247.	2025.		
Total	17	160856.			