



Original Paper

Intercropping for Resilient and Diversified Agri-Food Systems In Moisture-Stress Areas of Amhara

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Abstract— Intercropping is the practice of growing two or more crops together in the same piece of land, and at the same time—boosts yield stability, reduces risk, enhances food diversity, alleviates poverty, and strengthens climate resilience. This study evaluated sorghum-pulse intercropping effects on yield, food diversity, and land use efficiency under the moisture-deficit areas of Dengora and Kalay Gondar, Ethiopia, during the 2017-2018 cropping season. A randomized complete block design with nine treatments and three replications was used, including sole cropping of sorghum, green gram, and common bean, as well as intercropping systems (sorghum-green gram and sorghum-common bean) arranged in 1:1, 1:2, and 2:1 row ratios. The results showed that the maximum grain yield was obtained from both sole cropping treatments. All intercropping results showed that the land equivalent ratios were greater than one, indicating that intercropping is more efficient. The 1:1 sorghum-common bean intercropping system achieved the highest land equivalent ratio (1.4) and a significant intercropping advantage (4601-4837). Additionally, the 1:1 sorghum common-bean combination showed a 31% area time equivalent ratio advantage. Economic analysis revealed that the 1:1 sorghum common-bean arrangement yielded the highest net benefit (35,967 Ethiopian Birr). Based on agronomic performance and economic viability, the 1:1 sorghum common-bean intercropping system is recommended to enhance the resilience and diversification of the agri-food system in moisture-stress areas of Dengora and Kalay Gondar, Ethiopia, and similar agroecology.

Keywords— *Intercropping, Land equivalent ratios, Moisture stress*

I. INTRODUCTION

Ethiopia is characterized by poor soil fertility due to continuous cereal cropping without adequate use of chemical fertilizers [1]. Farmers in sub-Saharan African countries, including Ethiopia, are being denied more crop yields because they cannot afford to buy inorganic fertilizers to replace nutrient-depleted soils. The declining soil fertility, drought, as well as unreliable rain have increased the chance of failure in sole cropping systems within the country [2]. Sustainable production systems are essential for Ethiopian smallholder farmers to counteract declining yields from population growth, low soil fertility, drought, and erratic rainfall [3].

Intercropping is a long-standing, climate-smart practice in Ethiopia that enhances resilience, productivity, and sustainability for smallholder farmers [4]. This system grows two or more crops together in the same piece of land, and at the same time. It improves land productivity, stabilizes yields, and increases resilience to drought and climate variability [5]. Intercropping provides insurance against weather variability and soil fertility, making it a highly beneficial crop production system [6]. Cereal-legume intercropping outperforms sole cropping by boosting yields and improving soil fertility.

In the moisture-stress area of Ethiopia, drought, erratic rainfall, and poor soil fertility are the most biophysical bottlenecks to rising agricultural productivity and hence threaten food security [7]. Cereal-legume intercropping is a widely adopted practice that improves soil fertility, suppresses pests, diseases, and weeds, and reduces the risk of crop failure, making it a key strategy for sustainable and resilient agriculture [8], [9].

Cereal crops such as sorghum, teff, maize, and pearl millet are fundamental to Ethiopian agriculture, especially in dry land areas [10]. These crops are intercropped with nutrient-fixing legumes like common bean, soybean, and green gram, a practice that improves soil fertility, enhances climate resilience, and supports food security and rural livelihoods [11].

Intercropping provides multiple, well-documented benefits for resource-use efficiency, income, pest reduction, food diversification, crop resilience, and soil fertility [8]. Despite these well-documented benefits, farmers in the study area predominantly practice cereal with cereal intercropping, a system that limits productivity, increases pest pressure, limits food diversification, and accelerates soil nutrient depletion. Consequently, this practice constrains farmers' economic potential, and no comprehensive intercropping research has been conducted in the area to address these challenges. Therefore, this study was designed with the objectives of evaluating the effects of sorghum-pulse intercropping on yield, food diversification, and land-use efficiency in moisture-stress areas of Gondar, Ethiopia.

II. MATERIALS AND METHODS

The experiments were conducted 2017 and 2018 main cropping seasons at Dengora and Kalay, District of Central Gondar Zone, Ethiopia. The study was conducted 2017 and

2018 main cropping seasons at two farmers' fields in Dengora and Kalay District of Central Gondar Administrative Zone, Ethiopia. Dengora trial site has a latitude of about 13°12' 35" N and a longitude of 38°08' 25" E. The elevation of the trial site is 900 meters above sea level. The mean annual rainfall in the district is 612 mm. The annual temperatures range from 13-36°C, respectively. Kalay has a latitude of 13.133°N and a longitude of 37.900°E and an elevation ranging from 1100 to 1680 meters above sea level. The trial site of the district obtains an annual rainfall ranging from 700 to 823 mm. The annual temperature ranges from was 13-28°C. The sites are characterized by recurrent moisture stress, clay-textured soils, and erratic rainfall, making them suitable for evaluating drought-resilient cropping systems.

Nine intercropping treatments, including sole crops of sorghum, green gram, and common bean as well as various sorghum-pulse row arrangements (1:1, 1:2, and 2:1), were used and conducted in RCBD with three replications. Each plot measured 3.0 m × 4.5 m. Recommended spacing for sorghum (75 cm × 15 cm), common bean (40 cm × 10 cm), and green gram (30 cm × 5 cm). In the intercropped, legumes were planted 15 days after sorghum. All treatments received 100 kg ha⁻¹ DAP at planting. Sorghum plots were top-dressed with 50 kg ha⁻¹ urea at the knee-height stage. Composite soil samples were collected before and after planting, and analyses were done. All agronomic managements were practiced uniformly for each plot.

Days to emergence, Days to heading, Striga numbers, Days to maturity, plant height, head length, stand count at harvest, harvestable head number, 1000 seed weight, biomass yield, grain yield, harvest index, for sorghum, and days to flowering, days to maturity, nodule number per plant, numbers of pod per plant, number of seed per pod, pod length, 100 seed weight for pulses were collected. Land equivalent ratio, area time equivalent ratio, actual yield loss, intercropping advantage, and partial budget analysis were done to compare different cropping systems. Pre- and post-harvest soil analyses were collected for each treatment to characterize the experimental site and to see additional benefits from the intercrop.

The collected data were subjected to analysis of variance (ANOVA) using R software. Where a significant F-test was used and means comparison tests carried out using the Least Significant Difference (LSD) at $p \leq 0.05$. In addition, intercropping efficiency was assessed using indices such as land equivalent ratio (LER), Equation 1, area time equivalent ratio (ATER), Equation 2, actual yield loss, or gain (AYL), Equation 3, and intercropping advantage (IA), Equation 4.

$$LER = \left(\frac{Y_{am}}{Y_{as}} \right) + \left(\frac{Y_{bm}}{Y_{bs}} \right) \dots\dots\dots (1)$$

Where, Y_{am} and Y_{bm} are the yields of two crops in the intercropping, and Y_{as} and Y_{bs} are the yields of each crop in a sole cropping system. If LER is greater than one, intercropping would be better than monoculture [12].

$$ATER = \frac{L_{iti} + L_{jtj}}{T} \dots\dots\dots (2)$$

Where L_i and L_j are partial LER of component crops i and j , t_i and t_j are the duration for crops i and j , and T is the time of the whole intercropping system [13].

$$AYL = AYL_a + AYL_b$$

$$AYL_a = [LER \times (100/Z_{ab}) - 1]$$

$$AYL_b = [LER \times (100/Z_{ab}) - 1] \dots\dots\dots (3)$$

Where, AYL_a is the sown partial actual yield loss or gain of variety a , AYL_b is the sown partial actual yield loss or gain of variety b , Z_{ab} is the sown proportion of variety a in intercropping, and Z_{ba} is the sown proportion of variety b in intercropping [14].

$$LA = \left[\left(\frac{P_a}{P_a} + P_b \right) \times AYL_b \right] + \left[\left(\frac{P_b}{P_a} + P_b \right) \times AYL_a \right] \dots\dots (4)$$

In this comparison, P_a is the price of variety a , P_b is the price of variety b , AYL_a is the partial actual yield loss or gain of variety a , and AYL_b is the partial actual yield loss or gain of variety b [15].

III. RESULTS AND DISCUSSION.

A. Soil Data

The composite soil sample result showed that pre-planting soil analysis revealed low total nitrogen (0.062–0.072%) and medium available phosphorus [16]. The composite soil sample contributed 3.4–4.0% soil OM at both locations, which is rated as medium [17]. Soil pH values (7.8–8.1) were suitable for sorghum and most pulse crops in both locations. High cation exchange capacity (67–69 C mol kg⁻¹) indicated good nutrient-holding capacity, while low electrical conductivity confirmed non-saline conditions. Clay texture predominated across both locations [18] (Table 1).

TABLE I. SOME PHYSICO-CHEMICAL PROPERTIES OF THE SOIL BEFORE AND AFTER HARVEST EXPERIMENTAL FIELD

Soil sample pre-planting				
Location	Soil sample	Parameters		
		Total Nitrogen %	Available Phosphorus (ppm)	
Dengora	Composite	0.062	6.1	
Kalay	Composite	0.076	10.1	
Soil sample after harvesting				
Treatments	Dengora		Kalay	
	Total Nitrogen %	Available Phosphorus (ppm)	Total Nitrogen %	Available Phosphorus (ppm)
SS	0.019	12.8	0.07	11.7
SG	0.152	16	0.12	15.3
SC	0.254	16	0.285	14.5
1S:1G	0.075	12.5	0.089	12.4
1S:1C	0.079	17.1	0.089	14.4
1S:2G	0.082	9.9	0.087	11.6
1S:2C	0.093	18.9	0.092	17.7
2S:1G	0.067	10.7	0.094	12.6

SS=Sole sorghum, SG=Sole green gram, SC=Sole common bean, 1S:1G=Sorghum green gram row ratios, 1S:1C=Sorghum common bean row ratios, 1S:2G=Sorghum green gram row ratios, 1S:2C=Sorghum common bean row ratios, and 2S:1G=Sorghum green gram row ratios.

Post-harvest soil analysis in Table 1 showed notable improvements (0.02–0.29%) in total nitrogen under all treatments except sole sorghum, with the highest increments recorded under sole legumes and sorghum-common bean

intercrops [19]. Available phosphorus increased under sole green gram and sorghum-common bean intercropping systems. These findings confirm the soil fertility enhancement role of legumes, particularly under intercropping [20]. In general, the properties of the experimental soil and the weather conditions of the area were conducive to the growth of each crop.

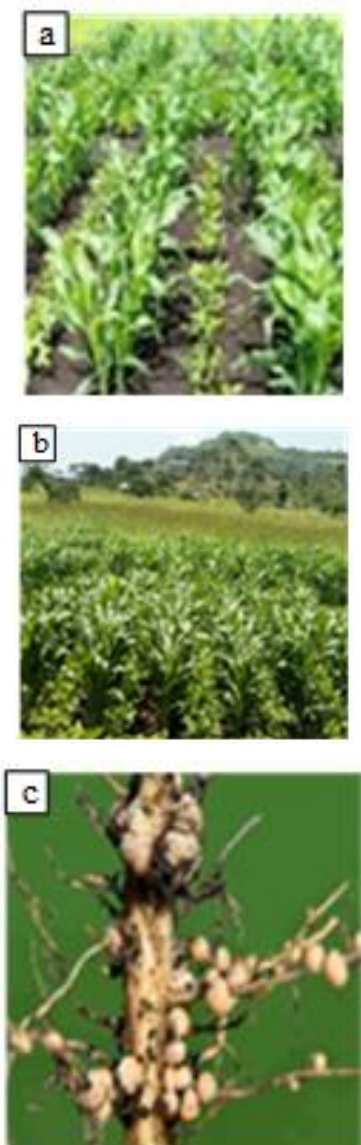


Fig. 1. Field performance of the intercropping trial conducted in the moisture-stress area of Belesa (a, b) field photos of the intercropping plots; (c) nodule number in the trial.

B. Sorghum Component

The combined analysis of variance exhibited that there were significant ($P < 0.01$) differences among varieties for Striga count, head length, 1000 seed weight, biomass, harvest index, and grain yield. As shown in Table 2, the maximum Striga count at Dengora was recorded for sole sorghum (84), while the lowest was recorded from treatment 1:2 sorghum-common bean row ratio (16). At Kalay, the highest Striga count was also recorded at sole cropping of sorghum (9), whereas the minimum Striga count (3.7) was recorded from the plot that received 1:2

sorghum-green gram. As a result, at both locations, the highest Striga count was recorded from sole sorghum treatment, which showed that the intercropping system can have reduced Striga weed pressure. Intercropping sorghum with legumes reduces Striga infestation through trap cropping, improved soil fertility, shading, and competition, making it a sustainable and effective management strategy for Striga control. The result of this investigation is also supported by those obtained by [21], [22].

TABLE II. EFFECTS OF LOCATIONS AND INTERCROPPING TREATMENTS ON STRIGA WEED POPULATION IN SORGHUM- PULSES INTERCROPPING AT DENGORA AND KALAY, 2017-2018

Treatments	Dengora	Kalay
SS	84.0 ^a	9.0 ^a
SG	-	-
SC	-	-
1S:1G	28.0 ^c	4.3 ^{bc}
1S:1C	18.0 ^d	4.0 ^c
1S:2G	16.3 ^d	3.7 ^c
1S:2C	16.0 ^d	4.0 ^c
2S:1G	58.0 ^b	7.7 ^a
2S:1C	56.7 ^b	7.0 ^{bc}
LSD (0.05)	5.7	2.7
CV (%)	8.1	27
Mean	10.2	2.3

**= Highly significant difference, *=significant differences, NS=Non-significant differences, CV=coefficient of variation, LSD=List significant differences, LS=List significant, SS=Sole sorghum, SG=Sole green gram, SC=Sole common bean, 1S:1G=Sorghum green gram row ratios, 1S:1C=Sorghum common bean row ratios, 1S:2G=Sorghum green gram row ratios, 1S:2C=Sorghum common bean row ratios, 2S:1G=Sorghum green gram row ratios, and 2S:2C=Sorghum common bean row ratios.

Maximum head length was recorded at sole sorghum (27.9cm), and the minimum head length was recorded in 1:2 sorghum-common bean intercropping row ratios (25.9cm) (Table 3). Sole cropping of sorghum consistently leads to longer panicles, which are strongly linked to higher grain yield. This finding is well-supported and aligns with previous research, highlighting the importance of panicle length as a potential trait for yield improvement in sorghum[23].

As shown in Table 3, the highest 1000 seed weight (24.5 g) was obtained from the 1:1 sorghum-common bean intercropping pattern, while the lowest 1000 seed weight (21.7 g) was obtained from the 2:1 sorghum green-gram intercropping system. The most probable reason for this variation could be due to the use of soil nutrients and water in the intercropped sorghum. The sunlight was probably not penetrating to the soil because of common bean was highly branched, leafy, used as mulching, and probably sorghum used the nodules that fix common bean from the atmospheric nitrogen. This finding is confirmed by the result of [24].

As shown in Table 3, the highest biomass accumulation was obtained from sole sorghum (15358.5 kgha-1), and the lowest biomass was recorded from treatments of 1:2 sorghum-common bean intercropping pattern (10699.1 kgha-1). This could be related to the general fact that crop density decreases the vegetative part of plants to give a higher biomass because there was no computation of nutrients, space, sunlight, or moisture. This finding is confirmed by the result of [25].

The highest grain yield was recorded from the sole sorghum treatment (4498.5 kg ha-1), while the lowest grain yield was obtained from the 2:1 sorghum-common bean row ratio

intercropping pattern (3269.7 kg ha⁻¹). The most probable reason for this variation could be due to interspecific competition for resources like soil nutrients, sunlight, space, and water in the intercropped sorghum. Different findings confirmed the recent study [9], [12], [21]. Based on the above-mentioned results and discussion, the diagram illustrating the performance of intercropping on biomass and grain yield was drawn in (Fig. 1a&b).

The highest harvest index was achieved at a 1:1 sorghum-common bean intercropping row ratio (35.6%), and the lowest was recorded in a 2:1 sorghum-common bean row ratio (27.1%) in Table 3. According to [26], harvest index positively correlated with grain yield but negatively correlated with vegetative growth.

TABLE III. THE COMBINED MEAN VALUE OF HEAD LENGTH, HARVEST INDEX, THOUSAND SEED WEIGHT, BIOMASS, AND GRAIN YIELD OF SORGHUM INTERCROPPING AT DENGORA AND KALAY, 2017-2018

Treatments	Parameter			
	HL (cm)	HI (%)	TSW (gm)	B (kg ha ⁻¹)
SS	27.9 ^a	29.3 ^{bc}	21.8 ^b	15358.5 ^a
SG	-	-	-	-
SC	-	-	-	-
1S:1G	27.1 ^{ab}	34.2 ^a	21.3 ^{bc}	12391.7 ^{cd}
1S:1C	27.8 ^a	35.6 ^a	24.5 ^a	12114.7 ^{cd}
1S:2G	26.2 ^b	30.8 ^b	20.2 ^c	11190.6 ^{dc}
1S:2C	25.9 ^b	30.6 ^b	23.2 ^a	10699.1 ^c
2S:1G	26.3 ^b	27.9 ^{bc}	20.5 ^{bc}	13690.8 ^b
2S:1C	26.6 ^{ab}	27.1 ^c	21.4 ^{bc}	13203.7 ^{cd}
LSD (0.05)	1.4	3.1	1.7	1281.9
CV (%)	4.5	8.6	6.1	8.5
Mean	26.8	30.8	24.1	12664.2

**= Highly significant difference, *=significant differences, NS=Non-significant differences, HL=Head length, HI=Harvesting index TSW=Thousand seed weight, B= biomass, T=treatment, CV=coefficient of variation, LSD=List significant differences, LS=List significant, SS=Sole sorghum, SG=Sole green gram, SC=Sole common bean, 1S:1G=Sorghum green gram row ratios, 1S:1C=Sorghum common bean row ratios, 1S:2G=Sorghum green gram row ratios, 1S:2C=Sorghum common bean row ratios, 2S:1G=Sorghum green gram row ratios, and 2S:2C=Sorghum common bean row ratios.

C. Pulses Component

The combined analysis of variance showed that there were significant (P<0.01) differences among the traits for biomass, number of pods per plant, and grain yield. Sole cropping of green gram (4856.8kg ha⁻¹) and common bean (3388.9kg ha⁻¹) gives the highest biomass yield in the treatment, while the lowest biomass (486.1 and 248.3kg ha⁻¹) was also recorded from 2:1 sorghum-green gram and 2:1 sorghum-common bean row ratio intercropping, respectively (Table 4). This result is due to the absence of interspecific competition, like shading effects. Different findings confirmed the recent study [24].

The highest grain yield was recorded from sole green gram (1920.5kg ha⁻¹) and common bean (1460.3kg ha⁻¹) treatments. The lowest grain yield was recorded from the intercropping treatments 2:1 sorghum-green gram (169.8kg ha⁻¹), and 2:1 sorghum-common bean row arrangements (266.3kg ha⁻¹). This result might be due to competition for light and other environmental growth resources in the intercropping of a pulse (Fig. 2). In conformity with this result [27].

The combined result of the number of pods per plant was higher in the case of sole cropping of green gram (13.6) as compared to all the intercropping patterns (Table 4). Possible

reason for the sole green gram plots might be attributed to no interspecific competition and fixed by the root nodule. Similar results are reported by [28], who observed that the number of pods per plant of green gram was higher in the sole cropping system as compared to their corresponding intercropped system.

The nodule number under monocropping of pulses was the highest, and increased significantly by 0.5 folds in 2017 compared with 2018 (Fig. 1c). As compared to the intercropping system, the highest nodule number was recorded in the 1:1 sorghum common bean intercropping system, and the lowest nodule number was shown in the 2:1 sorghum green gram intercropping system (Fig. 2). This reduction is attributed to competition for light, nutrients, and water, as well as shading from the taller cereal crop [29].

TABLE IV. THE COMBINED MEAN VALUE OF DRY BIOMASS AND NUMBER OF PODS PER PLANT ON GREEN GRAM AND COMMON BEAN AT DENGORA AND KALAY, 2017-2018

Treatment	Green gram		Common bean	
	B (kg ha ⁻¹)	NPP ⁻¹	B (kg ha ⁻¹)	NPP ⁻¹
SS	-	-	-	-
SG	4856.8 ^a	13.6 ^a	-	-
SC	-	-	3388.9 ^a	10.9
1S:1G	1132.1 ^c	10.0 ^b	-	-
1S:1C	-	-	1673.8 ^c	9.4
1S:2G	1715.0 ^b	10.3 ^b	-	-
1S:2C	-	-	2588.6 ^b	9
2S:1G	486.1 ^d	10.8 ^b	-	-
2S:1C	-	-	747.1 ^d	9.5
LSD (0.05)	418.3	1.6	248.3	-
CV (%)	20.1	20.7	9.5	17.4
Mean	2047.5	11.2	2099.6	9.7

**= Highly significant difference, *=significant differences, NS=non-significant differences, B=biomass, NPP⁻¹=Numbers of pod per plant, CV=coefficient of variation, LSD=List significant differences, LS=List significant, SS=Sole sorghum, SG=Sole green gram, SC=Sole common bean, 1S:1G=Sorghum green gram row ratios, 1S:1C=Sorghum common bean row ratios, 1S:2G=Sorghum green gram row ratios, 1S:2C=Sorghum common bean row ratios, 2S:1G=Sorghum green gram row ratios, and 2S:2C=Sorghum common bean row ratios.

D. Abbreviations and Acronyms

The land equivalent ratio (LER) greater than one had been achieved from a 1:1 sorghum-common bean intercropping pattern (1.4). Nevertheless, the lowest LER was recorded on treatments having a 2:1 sorghum-green gram intercropping ratio (0.9) (Fig. 3). Concerning the result in (Fig. 3), in all combinations, the LER was more than one except in the treatment that received 2:1 sorghum-green gram and 2:1 sorghum-common bean intercropping pattern which in turn validating that intercropping was less density and limited soil fertility significantly reduces the productivity of the intercropping system. The result of a land equivalent ratio more than one implied that intercropping is advantageous in many instances, rather than sole planting with respect to land area. A value of LER more than one is perhaps because of fixing atmospheric nitrogen into usable forms in intercropping sorghum and pulses. This finding is confirmed by the results of [4].

The highest area time equivalent ratio (ATER) was recorded in the combination of 1:1 sorghum-common bean row ratios (1.3) (Fig. 3). This indicating that the proper resource utilization

due to the high variations in the maturity periods of the crops in which sorghum stayed longer on the land and had enough time to fully mature and suggesting that 1:1 sorghum-common bean inter cropping is more advantageous in the test location, but the lowest also recorded in the combination of 2:1 sorghum-green gram and 2:1 sorghum-common bean row ratio (0.9). Whereas, 2:1 sorghum-green gram and 2:1 sorghum-common bean intercropping showed less than 1.0, thus indicating the disadvantage. This was in agreement with [4].

Actual yield loss or gain (AYL) is a sensitive indicator for yield gain or loss in sorghum-pulse intercropping systems. In this study, the highest amount of AYL/G was obtained in treatment 1:1 sorghum common-bean with 3.9 and followed by 1:2 sorghum-common bean with 3.4, while the lowest was obtained in treatments 2:1 sorghum-green gram and 2:1 sorghum common-bean row ratios with 2.2 and 2.4, respectively (Fig. 3). The reason for this result was due to the exhaustive effect of sorghum and early shading in the early growth stage of pulses. Similar results were also reported by [30].

According to the index, in addition to expressing the advantage or disadvantage of intercrops, it can be an indicator of the economic feasibility of intercropping systems. The positive intercropping advantage (IA) was recorded in the treatment 1:1 sorghum common-bean treatment, and 1:2 sorghum common-bean row ratio with 4601 and 4837, respectively [4], and the lowest IA was obtained in the treatment combination 2:1 sorghum-common bean row ratio with 2972 (Fig. 3). Probably reason for this result was due to better use of resources such as light, water, and nutrients in this treatment, probably.

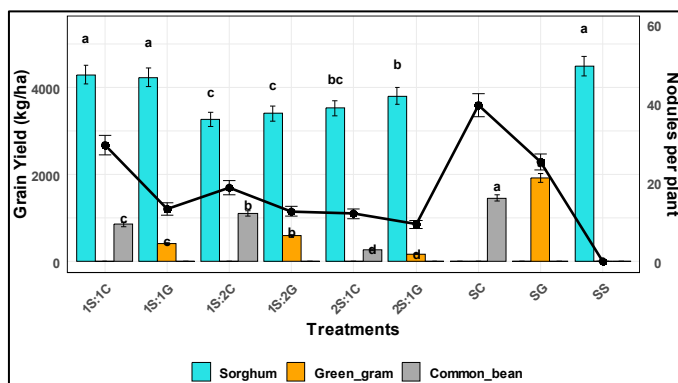


Fig. 2. Combined results of grain yield and nodule number per plant for the 2017-2018 seasons. Treatments include SS=Sole sorghum, SG=Sole green gram, SC=Sole common bean, 1S:1G=Sorghum green gram row ratios, 1S:1C=Sorghum common bean row ratios, 1S:2G=Sorghum green gram row ratios, 1S:2C=Sorghum common bean row ratios, 2S:1G=Sorghum green gram row ratios, and 2S:2C=Sorghum common bean row ratios.

Net benefit (NB) was determined to evaluate the economic advantage of an intercropping system as compared to sole cropping [31]. NB was computed from the yield of sorghum, green gram, and common bean intercropping by multiplying the yields by their respective unit price (Fig. 3). The total values obtained from the component crops were used to indicate the net benefit. According to [4], to estimate the NB of component crops, sorghum grain yield is valued at an average open market price of 9 ETB kg⁻¹, green gram 18 ETB kg⁻¹, and common

bean each at 13 ETB kg⁻¹ at the time of crop harvest in 2017-2018 at Belesa District, Gondar, Ethiopia. The intercropping system was economically feasible relative to a sole crop of maize as reported from different intercrop studies, including [32], [33].

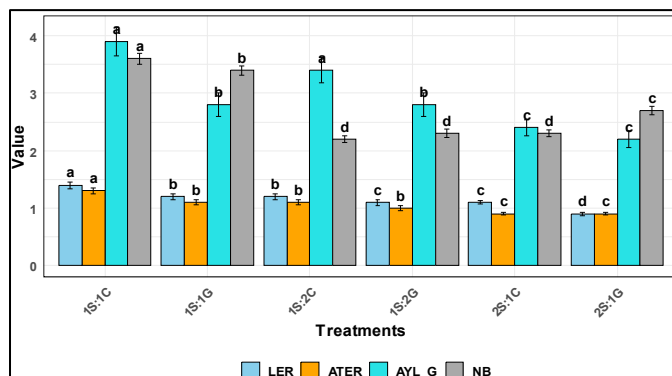


Fig. 3. Combined results of land equivalent ratio (LER), area time equivalent ratio (ATER), actual yield loss/gain (AYL/G), and net benefit (NB) for the 2017-2018 cropping seasons. Prices (ETB/kg): sorghum = 9 ETB, green gram = 18 ETB, and common bean = 13 ETB. Treatments: SS=Sole sorghum, SG=Sole green gram, SC=Sole common bean, 1S:1G=Sorghum green gram row ratios, 1S:1C=Sorghum common bean row ratios, 1S:2G=Sorghum green gram row ratios, 1S:2C=Sorghum common bean row ratios, 2S:1G=Sorghum green gram row ratios, and 2S:2C=Sorghum common bean row ratios, and ETB = Ethiopian birr.

IV. CONCLUSION AND RECOMMENDATION

The study confirms that a 1:1 sorghum common-bean intercropping row ratio arrangement is highly effective in suppressing *Striga* infestation while simultaneously enhancing diversification within the agri-food system. This cropping pattern strengthens climate resilience, stimulates nodulation, and improves soil fertility. In terms of agronomic efficiency indices (LER, ATER, AYL/G) and economic performance, the 1:1 sorghum common-bean row ratio intercropping system consistently outperformed all other tested row arrangements, delivering the highest net return and marginal rate of return. Crucially, this practice enables farmers to generate additional income without reducing sorghum yield. Beyond its agronomic and economic merits, the system allows for the independent management of both crops while reducing labor and time requirements during harvesting and threshing operations. Its resilience is particularly evident under low rainfall conditions, making it a robust option during seasons characterized by limited and uneven rainfall distribution. Accordingly, the adoption of a 1:1 sorghum common-bean intercropping system is strongly recommended as a strategy for sustainable intensification, enhanced profitability, diversifying the food system, and improved resilience in smallholder farming systems.

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REFERENCES

- [1] B. Bedadi, S. Beyene, T. Erkossa, and E. Fekadu, "Soil Management," in *The Soils of Ethiopia*, S. Beyene, A. Regassa, B. B. Mishra, and M. Haile,

- Eds., in *World Soils Book Series.*, Cham: Springer International Publishing, 2023, pp. 193–234. doi: 10.1007/978-3-031-17012-6_9.
- [2] H. G. Feleke, T. A. Amdie, F. Rasche, S. Y. Mersha, and C. Brandt, “Climate on the Edge: Impacts and Adaptation in Ethiopia’s Agriculture,” *Sustainability*, vol. 17, no. 11, p. 5119, 2025, Accessed: Nov. 21, 2025. [Online]. Available: <https://www.mdpi.com/2071-1050/17/11/5119>
 - [3] G. Zeleke Tessler and S. Demeke Molla, “Impact of Climate - Smart Crop Intensification on Rural Household Food Security in North Wollo Zone, Ethiopia,” *Plant Environ Interactions*, vol. 6, no. 3, p. e70062, Jun. 2025, doi: 10.1002/pei3.70062.
 - [4] A. Assefa, M. Abate, M. Haile, and Y. Hunegnaw, “Land productivity and economic benefit of sorghum (*Sorghum bicolor* L.), mung bean (*Vigna radiata* L.) intercropping using intercrop indices and Partial budget analysis in Lasta District, North Eastern Ethiopia,” *Discov. Plants*, vol. 2, no. 1, p. 153, May 2025, doi: 10.1007/s44372-025-00232-1.
 - [5] A. M. Adam et al., “Enhancing the resilience of intercropping systems to changing moisture conditions in Africa through the integration of grain legumes: A meta-analysis,” *Field Crops Research*, vol. 321, p. 109663, 2025, Accessed: Nov. 21, 2025. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0378429024004167>
 - [6] T. B. Mihrete and F. B. Mihrete, “Crop Diversification for Ensuring Sustainable Agriculture, Risk Management and Food Security,” *Global Challenges*, vol. 9, no. 2, p. 2400267, Feb. 2025, doi: 10.1002/gch2.202400267.
 - [7] S. Habtu, “Revitalizing key conditions and integrated watershed management to mitigate land degradation and sustain water availability for agriculture in semi-arid regions: A case study of Ethiopia,” *Qeios*, 2024, Accessed: Nov. 21, 2025. [Online]. Available: <https://pdfs.semanticscholar.org/c280/01292f9e38fd429db014d925cf79aca8973d.pdf>
 - [8] K. Akchaya et al., “Boosting resource use efficiency, soil fertility, food security, ecosystem services, and climate resilience with legume intercropping: a review,” *Frontiers in Sustainable Food Systems*, vol. 9, p. 1527256, 2025, Accessed: Nov. 21, 2025. [Online]. Available: <https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2025.1527256/full>
 - [9] S. Brahim, O. Toumatia, J. J. Drevon, A. Zitouni, and M. Lazali, “Intercropping legumes and cereals increases resource use efficiency and crop productivity in low phosphorus soils under semi-arid Mediterranean conditions,” *Agroecology and Sustainable Food Systems*, vol. 46, no. 10, pp. 1482–1501, Nov. 2022, doi: 10.1080/21683565.2022.2121951.
 - [10] A. Ruiz-Giral, S. Biagetti, M. Madella, and C. Lancelotti, “Small-scale farming in drylands: New models for resilient practices of millet and sorghum cultivation,” *PLoS One*, vol. 18, no. 2, p. e0268120, 2023, Accessed: Nov. 21, 2025. [Online]. Available: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0268120>
 - [11] V. G. P. Chimonyo et al., “Can cereal-legume intercrop systems contribute to household nutrition in semi-arid environments: A systematic review and meta-analysis,” *Frontiers in nutrition*, vol. 10, p. 1060246, 2023, Accessed: Nov. 21, 2025. [Online]. Available: <https://www.frontiersin.org/articles/10.3389/fnut.2023.1060246/full>
 - [12] R. Willey, “Intercropping-its importance and research needs. 1. Competition and yield advantages,” 1979, Accessed: Nov. 22, 2025.
 - [13] I. Yahuza, “Review of some methods of calculating intercrop efficiencies with particular reference to the estimates of intercrop benefits in wheat/faba bean system,” *International Journal of Biosciences*, vol. 1, no. 5, pp. 18–30, 2011, Accessed: Nov. 22, 2025.
 - [14] B. Singh, A. K. Dhaka, S. Kumar, S. Singh, and M. Kumar, “Land, biological and economic evaluation of intercropping systems involving barley (*Hordeum vulgare*), Indian mustard (*Brassica juncea*) and chickpea (*Cicer arietinum*) under different spatial arrangements,” *Indian Journal of Agronomy*, vol. 62, no. 4, pp. 443–450, 2017, Accessed: Nov. 22, 2025. [Online]. Available: <https://pub.isa-india.in/index.php/ija/article/view/5548>
 - [15] F. Baraki, Z. Gebregergis, G. Teame, and Y. Belay, “Augmenting productivity and profitability through Sesame–Legume intercropping,” *Heliyon*, vol. 9, no. 7, 2023, Accessed: Nov. 22, 2025. [Online]. Available: [https://www.cell.com/heliyon/fulltext/S2405-8440\(23\)05541-X?uuiid=uid%3A00692f26-4658-48dc-b17b-6b88e305c5c8](https://www.cell.com/heliyon/fulltext/S2405-8440(23)05541-X?uuiid=uid%3A00692f26-4658-48dc-b17b-6b88e305c5c8)
 - [16] C. P. Murphy and R. A. Kemp, “The over - estimation of clay and the under - estimation of pores in soil thin sections,” *Journal of Soil Science*, vol. 35, no. 3, pp. 481–495, Sep. 1984, doi: 10.1111/j.1365-2389.1984.tb00305.x.
 - [17] N. M., “The Role of Organic Matter in Soil for Improving Crop Productivity and Soil Health,” *Journal of Experimental Agriculture International*, 2025, doi: 10.9734/jeai/2025/v47i23296.
 - [18] W. Mengiste, D. Tsegaye, S. Dagalo, and T. Yitbareke, “Characterization and classification of soils in the irrigable land of Achewa small-scale irrigation area, Itang special district, southwest Gambella, Ethiopia,” *Front. Soil Sci.*, vol. 4, Jan. 2025, doi: 10.3389/fsoil.2024.1451271.
 - [19] M. A. Raza et al., “Maize/Legume Intercropping Increases Nutrient Uptake, Crop Yields, Land Productivity, and Economic Profits in Resource-intensive Arid-irrigated Areas,” *J Soil Sci Plant Nutr*, vol. 25, no. 3, pp. 8316–8332, Sep. 2025, doi: 10.1007/s42729-025-02675-7.
 - [20] D. Temeche, E. Getachew, G. Hailu, and A. Abebe, “Effect of Sorghum-Mung Bean Intercropping on Sorghum-Based Cropping System in the Lowlands of North Shewa, Ethiopia,” *Advances in Agriculture*, vol. 2022, pp. 1–7, Apr. 2022, doi: 10.1155/2022/6987871.
 - [21] A. A. Abbasher, M. S. Zaroug, E. B. Zahran, and D. A. Dawood, “Influence of Sorghum-legume Intercropping on Striga Control and Sorghum Performance,” *University of Khartoum Journal of Agricultural Sciences*, vol. 21, no. 2, 2023, Accessed: Nov. 23, 2025. [Online]. Available: <https://www.academia.edu/download/101283969/1654.pdf>
 - [22] F. Merkeb, Z. Melkei, T. Bogale, and A. Takele, “Influence of intercropping sorghum with legumes to control striga (*Striga hermonthica*) in Pawe, North Western Ethiopia,” vol. 53, pp. 204–215, 2016, Accessed: Nov. 23, 2025. [Online]. Available: <https://consensus.app/papers/influence-of-intercropping-sorghum-with-legumes-to-merkeb-melkei/2c993ee9ba0d53da8827b576449790bf/>
 - [23] M. Chibvongodze et al., “Potential traits for aiding selection for high grain yield based on trait association and path analysis in sorghum,” *Journal of Underutilised Crops Research*, vol. 4, no. 1, p. a23, Jun. 2025, doi: 10.4102/jucr.v4i1.23.
 - [24] M. Ashenafi, T. Wodimu, S. Tenaye, T. Kebede, and D. Alemu, “Assessing the Advantages of Sorghum–Haricot Bean Intercropping Over Sole Cropping and Productivity via Competitive Indices in Ethiopia’s Highland Regions,” *Advances in Agriculture*, vol. 2025, no. 1, p. 8847195, Jan. 2025, doi: 10.1155/aia/8847195.
 - [25] A. R. Dzvene, W. A. Tesfahuney, S. Walker, and G. Ceronio, “Optimizing the planting time and stand density of sunn hemp intercropping for biomass productivity and competitiveness in a maize-based system,” *Field Crops Research*, vol. 304, p. 109179, 2023, Accessed: Nov. 23, 2025. 6
 - [26] S. Widodo et al., “Sorghum Productivity and Its Farming Feasibility in Dryland Agriculture: Genotypic and Planting Distance Insights,” *Phyton* (0031-9457), vol. 93, no. 5, 2024, Accessed: Dec. 09, 2025.
 - [27] M. Ashenafi, T. Wodimu, S. Tenaye, T. Kebede, and D. Alemu, “Assessing the Advantages of Sorghum–Haricot Bean Intercropping Over Sole Cropping and Productivity via Competitive Indices in Ethiopia’s Highland Regions,” *Advances in Agriculture*, vol. 2025, no. 1, p. 8847195, Jan. 2025, doi: 10.1155/aia/8847195.
 - [28] K. S. Shaker and S. Nasrollahzadeh, “Evaluation of yield and advantage indices of sorghum (*Sorghum bicolor* L.) and mungbean (*Vigna radiata* L.) intercropping systems,” 2014, Accessed: Dec. 09, 2025. [Online]. Available: https://www.sid.ir/en/VEWSSID/J_pdf/57000020140118.pdf
 - [29] P. Lin et al., “Relay intercropped soybean promotes nodules development and nitrogen fixation by root exudates deposition,” *Frontiers in Plant Science*, vol. 15, p. 1447447, 2024, Accessed: Nov. 26, 2025.
 - [30] L. Zhou, L. Su, H. Zhao, T. Zhao, Y. Zheng, and L. Tang, “Maize/soybean intercropping improves yield stability and sustainability in red soil under different phosphate application rates in southwest China,” *Agronomy*, vol. 14, no. 6, p. 1222, 2024, Accessed: Dec. 09, 2025. [Online]. Available: <https://www.mdpi.com/2073-4395/14/6/1222>
 - [31] A. R. Ngwira, J. B. Aune, and S. Mkwinda, “On-farm evaluation of yield and economic benefit of short-term maize legume intercropping systems under conservation agriculture in Malawi,” *Field Crops Research*, vol. 132, pp. 149–157, Jun. 2012, doi: 10.1016/j.fcr.2011.12.014.

[32] N. Kawasaki et al., "Performance of maize, soybean, and mung bean intercropping systems in East Java, Indonesia," *Field Crops Research*, vol. 333, p. 110015, Nov. 2025, doi: 10.1016/j.fcr.2025.110015.

[33] M. Srinivasa Rao et al., "Impact of intercropping and low-external input integrated pest management on *Spodoptera frugiperda* (J. E. Smith) in maize," *Field Crops Research*, vol. 326, p. 109868, May 2025, doi: 10.1016/j.fcr.2025.109868.