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RESEARCH PAPER

Effect of Population Densities of Mung Bean (*Vigna radiata L.*) and Row Arrangements of Sorghum (*Sorghum bicolor* L.) Mung Bean Intercropping on the Productivity of Component Crops in Lasta District, North Eastern Ethiopia

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ABSTRACT

A field experiment was conducted during the 2022 main cropping season to determine the optimum population density of mung bean and row arrangement of sorghum-mung bean intercropping for enhancing the productivity of the systems. RCBD factorial combinations of three population densities of mung bean (50%, 67%, and 100% with three-row arrangements (1S:1M, 2S:1M, and 3S:1M), with sole sorghum and sole Mung bean as check was used. Data on phenology, growth, yield, and yield-related parameters of the experimental crops were taken and analyzed using SAS soft wear. Land equivalent ratio, competitive ratio, area time equivalent ratio, monetary advantage index, and MRR analysis were used for estimating the economic feasibility of the intercropping. The highest grain yield of sorghum (3030.93 kg ha^{-1} and 3020.43 kg ha^{-1}) was obtained within 2S:1M and 67% and 1S:1M and 50% of row arrangement and population density of mung bean, respectively. The highest yield of mung bean (626.37 kg ha^{-1}) was in a 1S:1M row arrangement with 100% population density of mung bean. The highest LER (1.35), monetary advantage index (21493 ETB ha^{-1}), net benefit (83309 ETB ha^{-1}), and acceptable MRR% (125.34) were obtained in 1S:1M with 50% population density of mung bean. Intercropping sorghum in a 1:1 row arrangement within 50% population density of mung bean gives 12.54 and 63.65% yield advantages and up to 21.43% and 45.27% ETB ha^{-1} net benefit advantages respectively than planting sorghum and mung bean alone. Therefore, 1S:1M row arrangements with a population density of 50% (125,000 plants ha^{-1}) are recommended for intercropping in the target area, based on its better compatibility, productivity, and economic benefit.

HIGHLIGHTS

- The trail was conducted to determine optimum plant population density of mung bean when intercrop with sorghum.
- Heights seed yield of mung bean was obtained when 100% population density of mung bean intercrop with sorghum.
- Maximum TLER (total land equivalent ratio) was obtained when 50% population density of mung bean intercrop with sorghum.
- The highest monetary advantage index (21493 ETB ha^{-1}) and net benefit (83309 ETB ha^{-1}), were obtained in 1S:1M with 50% population density of mung bean.

Keywords: Intercrop, LER, MAI, Mung bean, population density, Sorghum

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Sorghum belongs to the genus Sorghum, tribe *Andropogoneae*, of the Poaceae family (Clayton and Renvoize, 1986). It originated in Sub-Saharan Africa, and is a major food crop in arid and semi-arid regions of the world.

Nigeria: 7,000,000, United States: 5,989,000, Sudan: 5,000,000, Mexico: 4,850,000, Ethiopia: 4,500,000, India: 4,400,000, Argentina: 3,800,000, China: 3,000,000, Brazil: 2, 940, 00 are the major sorghum producers in the world respectively (USAD, 2023). Oromiya, Amhara, and Tigray, accounting for 86% of the total area and 89% of the production and it covers an area of 1,679,277.06 hectares of land with the production of 45,173,502.18 quintals on the productivity of 26.90 q ha^{-1} and in Amhara region, it also covers 597,440.83 with production of 15,881,921.36 in quintals and productivity of 26.58 q ha^{-1} (CSA, 2021) and based on the CSA (2021) data sorghum cover 56,953.34 areas with production in quintal 1,491,812.58 and a productivity of 26.19 q ha^{-1} at zonal level and based on Last District Agricultural office (LDAO, 2023) report, sorghum covers an area of 4819 ha with production 72110 quintal and with a productivity of 14.96 q ha^{-1}. The crop is produced for its grain, which is used for food, and stalks used for fodder and building materials in developing countries. It has tremendous uses for the Ethiopian farmer at the household level and no part of this plant is ignored (Amelework *et al*. 2016). Mung bean is one of the most important pulse crops, grown from the tropical to sub-tropical areas around the world (Kumari *et al*. 2012; Khan *et al*. 2012). Primarily, the purposes of this crop are for its protein rich edible seeds and fresh sprout, for making soups, bread and biscuits (Sehrawat *et al*. 2013). Earliness in maturity, low water requirement, ability to increase soil fertility and ideal in intercrop and crop rotation practices are some significances of mung bean (Das *et al*. 2014) and it is also used as a green manure crop and as forage for livestock (Mohammed *et al*. 2017). It is consider as the main cash and the most commodity exchange crop in Ethiopia (Ashenafi, 2016).

In Ethiopia, it covers 48,022.34 hectares of land with the production of 515,686.55 quintals and productivity 10.74 q ha^{-1} (CSA, 2021) and in Amhara region it covers 32,666.15 area with the production of 370,754.97 and productivity of 11.35 q ha^{-1} (CSA, 2021). But as mung bean is newly introduced low land pulse crop in Ethiopia, it is also new crop for lasta even if small holder farmers are cultivated it as intercrop with sorghum and as crop rotation, no CSA data on the area coverage, production and productivity up to 2023 in lasta district..

Intercrop is the simultaneous growth of two (or more) crop species in the same field area for all or part of their growing period (Dong *et al*. 2018). Cereal legume intercropping is a predominant cropping system in Sub-Sahara African countries where it is used for maximizing use of limited farmlands, food security and improving soil fertility (Kinde *et al*. 2016). A major benefit of intercropping is increase production per unit area compared to sole cropping through the effective use of resources (Jalilian *et al.* 2017), provides a balanced diet, minimizes risks of crop failure due to adverse effects of pests, improves the use of limited resources, reduces soil erosion, increases yield stability and provides higher returns (Ashenafi, 2016). It is the right strategy to feed the growing population (Gebremichael *et al*. 2019).

Plant density (plant population) which is simply defined as the number of individual plants per unit ground area is an important agronomic factor that manipulates micro environment of the field and affects growth, development and yield of crops (Caliskan *et al.* 2007; Seran *et al.* 2009). Plant population density can determine the success or failure of intercropping as well as the degree of competition among component crops. Plant density is therefore an important factor determining the economic viability of an intercropping system (Daroish *et al*. 2005). The overall mixture densities and the relative proportions of the component crops are important in determining the yields and production efficiency of cereal-legume intercrop systems (Willey and Osiru, 1972).

The research hypothesis is that different population densities of mung bean and row arrangements of sorghum-mung bean intercropping can have a significant impact on the yields of the component crops. The study was designed to test this hypothesis through field experiments using different treatment combinations of mung bean population densities and row arrangements of sorghum-mung bean intercropping. The expected outcomes of the study could include identifying the optimal population densities and row arrangements that can produce the highest yields, as well as identifying any interactions that may exist between the two crops in terms of competition for resources such as light, water, and nutrients. Additionally, the study could provide valuable insights into the potential benefits of intercropping as a sustainable farming practice that can improve yields and crop diversity while reducing the need for chemical fertilizers and pesticides.

Overall, the results of this study have the potential to inform farmers and policymakers in Lasta District and beyond on best practices for intercropping mung bean and sorghum. Also Sekota Dry land Agricultural Research Center has recommended Rassa (N-26), a mung bean and a sorghum variety Melkam for the study area. However, there is a lack of information on plant population density of mung bean when intercropped with sorghum and sorghum mung-bean intercrop row arrangement in lasta district. As a result, intercropping sorghum and mung bean in appropriate plant population density of mung bean and row arrangement are an excellent research topic in the study area (lasta). Furthermore, no research has been conducted in the study areas on the effects of plant density of mung bean and intercropping row ratio of mung bean with sorghum on yield and economic benefits of the cropping system and thereby it is difficult to recommend intercropping row ratio of mung bean with sorghum in the study area.

Therefore, the present study was conducted with the objectives of:

- To investigate the effect of mung-bean population density and sorghum-mung-bean intercrop arrangements on yield and yield attributes of component crops and
- To identify economically optimum mung-bean population density and sorghum-mung-bean intercrop row arrangements to enhance yield of component crops.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at Lasta District Lalibella town specifically at Shemseha (nearest to Lalibella airport), north wollo Zone, in Amhara Region under rain fed condition (*meher* cropping seasons) during 2022 cropping (Fig. 1). The area is located in the east part of Ethiopia at far from 637.5 km far away from Addis Ababa (capital of Ethiopia) and 302 km far from Bahir-Dar (capital of regional state of Amhara Region). It exists within the eastern Ethiopian of the Amhara region, at north wollo Zone. The area is characterized by a unimodal rainfall pattern that extends from June to late August or early September. The agro ecology of the district is varying from Woyna Dega (midlands) to kola (lowland). The geographical coordination of the research site is 11^0 58′ 18″ N latitude 38^0 58′ 54″E longitude with an altitude of 1963 meters above sea level (m.a.s.l). The mean annual minimum and maximum rainfall are 569 mm and 760 mm respectively. The site has a mean maximum (24.70^C) and minimum (13.60^C) temperature.

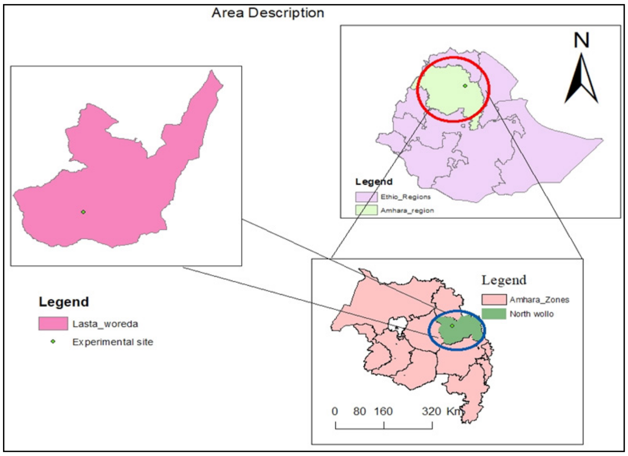

Fig. 1: Location of the study area at lasta District during 2022 cropping season

Usually sole cropping, mixing cropping without specific row arrangement and appropriate plant population density, crop rotation without keeping legume cereal principle is the major practices. Sorghum (*sorghum bicolor*), tef (*Eragrostis tef* (zucc.) (Trotter), barley (*Hordeum vulgare L.*), wheat (*Triticum aestivum L.* and *Triticum turgidum var. durum*), faba bean (*Vicia faba)*, Lentil (*Lens culinaris*), mung bean (*Vigna radita L.*), haricot bean (*Phaseolus vulgaris L.*) are some of the crops grown in the area (Lasta district). Intercropping of sorghum with mung bean, sorghum with haricot bean, tef with saff follower, sorghum with faba bean, sorghum with tef and wheat with sun follower are the most common cropping system in the study area (Mekonene and Daniel, May 20, 2021 and personal observation).

Experimental Materials

1. Plant Materials used for the experiment

Early maturing sorghum variety namely melkam was used as main crop for the study. Variety melkam has been recognized and recommend as high yielder and early maturing crop variety in the study area. Mung bean varieties Rasa (N-26) which is released by MARC in 2011 was used as the companion crop in additive series. The two crop species were selected for intercropping with sorghum based on their adaptability in the area, differences in their morphological characteristics and yield potential (Table 1).

2. Fertilizer materials and Application

A blanket recommendation of 100 kg NPSB (18.9, 37.7, 6.9, and 0.1%) $ha^{-1}$and 50 kg Urea (46 % N) ha^{-1} for all sole sorghum and intercropped sorghum plots was used. Half of nitrogen was applied during planting whereas the remaining half of nitrogen was top-dressed at knee-height stage of sorghum (when the sorghum plant produced 6-8 leaf) and full dose of NPSB was applied during planting. For the sole treatment of mung bean 100 kg NPSB ha^{-1} were used and applied fully at the time of planting. No nitrogen fertilizer was applied for the sole treatment of mung bean.

Treatments and Experimental Design

The experiment were arranged in a randomized complete block design and replicated three times. The treatment was consisted a total of 11 treatments and each treatment was randomly assigned to the experimental unit within a block. Three inter cropping pattern (1S:1M, 2S: 1M, and 3S:1M row arrangement in additive series in symmetrical way) with three mung bean planting densities D1, (50%), D2 (67%), and D3 (100%) along with sole crops of sorghum and mung bean. The size of each plot was 5 m × 3.75m (18.75 m^2) in a net plot size of 11.25 m^2 and pathways between plots and blocks were 0.5 m and 1 m, respectively.

There were 5 rows and nearly 33 plants maintained per row in a plot for main crop (sorghum) with spacing of 0.75 m and 0.15 m between rows and plant respectively which results in 88,889 and 166.65 plants was used per hectare and per plot respectively.

40 cm for sole treatments of mung bean inter-row was used while the intra-row spacing was varying based on the treatment. The intra row spacing was 10 cm (100%), 15 cm (67%), and 20 cm (50%) respectively. Sole cropping and inter cropping of sorghum was equal in population (88,889) plants because as the design follow additive series principles, the sorghum plant population is remain the same (100%) for inter cropped and sole sorghum

For sole mung bean crop there was 9 rows and 50 plants per row in a plot respectively. The mung bean plant densities were obtained by varying spacing between plants with in a row (i.e., 10, 15, and 20 cm. The experimental plant population densities were, D1, (100%), D2, (67%) and D3, (50%) plants per hectare respectively. Both the intercropped and the sole sorghum and mung bean net plot size was 3 m × 5m (15 m^2) and 2.95m × 5m (14.75m^2) respectively.

Experimental Procedures

1. Field Activities and Treatment Application

The experimental land (plot) was prepared and uniformly labeled in May and late June 2022. Seeds of sorghum and mung bean for the experimental purpose were collected from Melkasa and Gondar Agricultural Research center. Seeds of both crops were subjected to germination test to check their viability prior to sowing either to adjust the seed rate based on the germination percentage or to change the variety used. Seeds of the main (major)

Table 1: Description of experimental materials at Lasta District during 2022

Tested Variety	Years of Release	Days to maturity	Maturity Group	Alit (m)	RF (mm)	Released institute	Yield on station	Yield on farm
Melkam	2009	118	Early matured	<1600	Up to 800	MARC	3.7-5.8 t ha^{-1}	4.3 t ha^{-1}
(N-26) Rasa)	2011	65-80	Early maturing	900-1670	350-550	MARC	0.8-1.5 t ha^{-1}	0.5-1 t ha-^{1}

Where MARC = Melkassa Agricultural research center, Alit = Altitude, RF = rainfall, t = tone.
Source: *(MOARD, 2009; MOA, 2011).*

and the companion (additional) crop were sown in each plot uniformly by hand drilling into rows at the recommended rate of 15 kg ha^{-1} for sorghum and various seed rates of mung bean. For sorghum, seed drilling were sown per row in June 22, 2022 followed by thinning on the spacing of 0.15 m between plants after two weeks of emergence.

Two seed per pit of mung bean was sown in July 1, 2022 after fully emergence of the main crop and just to 2 weeks after emergence thinned to one plant per hole was done for mung bean intercropped and sole plot. A two times Karate chemical (0.4 L chemical dissolved by 200 L water ha^{-1}) was spray immediately on the emergence of mung bean when foliage beetles are observed on the leaf of the mung bean to control flea beetles *(Trirhabda flavolimbta)* and the second spray was after seven days next to the first spray. All agronomical practices were applied in each experimental plot equally. A two time's hand weeding was done uniformly at the same time for all experimental plots.

Data Collection and Measurements

1. Phenological and growth parameters of sorghum

1.1. Days to heading*:* was taken as the number of days required from planting to heading production by 50% of sorghum plants in the plots.

1.2. Days to Physiological Maturity (DPM): was recorded as the number of days required from planting to maturing by 90% of sorghum plants in the plots shows yellowing in leaf and hardening of the seed of sorghum plants in the plots.

1.3. Plant Height (cm): was measured as the height from the soil surface to the base of the heading of ten randomly taken plants from the net plot area using measuring meter at physiological maturities and the average was taken for analysis.

1.4. Panicle length (cm): panicle length from the ten sampled plants from the central rows of each plot was measured in cm and averaged to represent the panicle length

2. Yield Components and Yield of Sorghum

2.1. Thousand Kernels Weight (g): was determined by putting 1000 kernels into three replications and weighting them separately using sensitive balance and finally their averaged weight was taken.

2.2. Grain Yield (kg ha^{-1}): After harvesting, the seeds were threshed manually, cleaning, drying and yield was measured using electronic balance per net plot base and then adjusted to 14% seed moisture content using a digital moisture tester and converted to hectare basis. Adjusted yield was calculated using Hellevang (1995) formula.

Adjusted grain yield = 100-grain moisture content /100- standard grain moisture content × Obtained yield per plot.

2.3. Above Ground Biomass (t ha^{-1}): was measured from the net plot area in two stages. In the first heads of sorghum only was used and after a two weeks the leaves and the stems are harvested and summation of the head and other parts of each plot were weighed after three days of sun drying.

2.4. Harvest Index (%): was calculated as the ratio of grain yield to above ground biomass and multiplied by 100 and expressed as percentage. It was expressed as economic yield to biological yield and multiplied with 100 to convert in percentage.

3. Phenological and growth Parameters of Mung Bean

3.1. Days to Flowering: were determined as the number of days from planting to the period when 50% of the plants in each plot produce their first flower.

3.2. Days to Physiological Maturity: was taken as the number of days from planting to the period when 90% of the plants in a plot were changed the foliage (turned to yellow) and pod color and seed hardening in the pods. It was indicated by senescence of the leaves as well as frees threshing of the seeds from the pods when pressed between the forefinger and thumb.

3.3. Plant Height (cm): was measured as the height from the soil surface to the tip of ten randomly taken plants from the net plot area at physiological maturity and the average was taken for analysis.

4. Yield Components and Yield of mung Bean

4.1. Number of Pods per Plant: were counted from ten randomly selected haricot bean plants at physiological maturity and the average were recorded for each plot.

4.2. Number of Seeds per Pod: was recorded from ten randomly selected pods and the average was taken.

4.3. Thousand Seed Weight (kg): was determined from 1000 seeds randomly taken from each plot and weighed using sensitive balance and adjusted to 10% seed moisture content.

4.4. Seed Yield (kg ha^{-1}): was measured using electronic balance (steelyard) and then adjusted to 10% seed moisture content using digital moisture tester and converted to hectare basis. Adjusted yield was calculated by using the following formula (Hellevang, 1995).

Adjusted seed yield = 100-seed moisture content / 100 – standard grain moisture content × obtained yield per plot.

4.5. Above Ground Biomass (ton ha^{-1}): was determined after sun drying of the net plot area at 72 hours through measuring its weight after consecutive one-day interval before threshing till it maintains constant dry weight.

4.6. Harvest Index (%): was calculated as the ratio of grain yield to aboveground biomass and multiplied by 100 and expressed as percentage (Donald, 1962). It was expressed by the following formula.

HI = grain yield or economic yield / Biological yield (above ground biomass) × 100.

6. Analysis of Productivity and Benefit of inter crop system (system productivity analysis)

6.1. Land equivalent ratio (LER)

Land equivalent ratio (LER) is used as the criterion for mixed stand advantage. In particular, LER indicates the efficiency of intercropping for using the resources of the environment compared with mono cropping (Willey, 1980). The value of unity is the critical during intercrop principles. When the value of unity is greater than one, the intercropping favors the growth and yield of the species and economically justified. In contrast, when value of unity is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures and it is economically unjustified (Ofori, 1987). It is an indicator of complementarity and was calculated according to Willey and Osiru (1972) as yield of *YAB* / *YAA* + *YBA* / *YBB*. Where; *YAB* = yield of crop A (sorghum) when intercropped with crop B (mung bean) *YBA* = Yield of crop B (mung bean) when intercropped with crop A (sorghum) *YAA* = Yield from sole planted crop A (sorghum) *YBB* = Yield from sole planted crop B (mung bean).

6.2. Competitive ratio (CR)

The CR gives a better measure of competitive ability of the two inter crop crops. It is an indicator of competitiveness of the two inter crop species. The CR was calculated according to the formula developed by Willy and Rao (1980) as *CR = Yab /Yaa (zab)/Yba/Ybb (zba)* and the productivity is based on the value of unity. If CR > 1, indicate the first crop is more competitor, while values < 1 implicates the second component crop is profusely suppressed the first crop.

6.3. Area time equivalent ratio (ATER)

ATER provides more realistic comparison of the yield advantage of intercropping over mono cropping in terms of time taken by component crops in the intercropping systems than LER and it was as *RYA × ta + RY B × tb / T*. Where *YA* = relative yield of crop *A*, *ta* = the time taken by crop *a*, *RYB* = relative yield of crop *B*, *Tb* = the time taken by crop *B* and *T* = the total time taken by the system and its interpretations is based on the value. If ATER > 1, yield advantage and if ATER < 1, yield disadvantage as well as if ATER =1 no effect of intercropping; ATER <1 shows yield disadvantages.

6.4. Gross monetary values (GMV)

Gross monetary value was calculated based on (Willey, 1979) as a product of yield of component crops multiplied by their respective unit prices at the time of harvesting existing in the local market. The prevailing prices during harvesting in the local market (around Lalibela) was 21 Birr per kg for sorghum and 48 Birr per kg for mung bean were used for grain purpose

6.5. Monetary advantage index (MAI)

It was also calculated to give some economic evaluation of intercropping as compared to sole cropping. The monetary advantage index (MAI) was calculated using the formula developed by Willey (1979) as MAI is equal to the value of combined intercropped yield × (LER-1) / LER.

7. Economic analysis

Partial budget analysis is a method of organizing experimental data about the cost benefit of some changes (CIMMYT, 1988). It was calculated income and expenses based on variable cost. The mean grain yield and Straw yield data of sorghum and the grain yield of mung bean were adjusted down by 10% (to reduce the grain and biomass yield gap between experimental plots and farmers yield) partial budget analysis following the CIMMYT partial budget methodology (CIMMYT, 1988). The growth benefits (GB) were calculated by multiplying the yield by corresponding price for each treatment for mung bean and for sorghum, its grain yield with its price and its straw yield times with its price at harvest. Total variable costs (TVC) (seed of mung bean, chemical and labor cost) for each treatment were calculated and added. Net benefit (NB) per hectare was calculated by deducting TVC per hectare from GB per hectare. Then treatments were ranked in order of ascending total variable cost (TVC) and dominance analysis was used to exclude dominated treatments from further analysis those treatments costing more but producing a lower net benefit than the next lowest cost treatment. The cost of chemical, labor and seed were varying according to the population density of mung bean. The cost of improved sorghum variety seed was constant (25 Ethiopian birr kg^{-1}) and the total seed in ha^{-1} was 15 kg whereas mung bean seed was varying depends on population densities which were (80 birr and the seed rate of each population density were 21.12 kg, 11.8kg, and 7.04 kg for D1, D2, and D 3 respectively) and the chemical cost was 950 Birr for 0.5 L and it vary based on the population density of mung bean.

Marginal rate of return (MRR) was also calculated by dividing the change in NB to change in TVC and multiplied by hundred. Calculation of MRR used to show acceptable range between treatments. MRR below hundred is not acceptable range for developing countries like Ethiopia. A treatment having acceptable MRR and highest NB is said to be economically profitable and will be recommended for farmers (CIMMYT, 1988). Since the Straw yield of mung bean was not marketable, it didn't make cost benefit analysis. Gross benefit is the product of the yield times its price and the stalk yield times its price in sorghum and the total variable cost is the sum of all costs which vary between treatments (mung bean seed due to population densities which relates to seed rates and chemical cost for flea beetles). The MRR was calculated the change in net benefit to the change in total variable cost times hundred. Before calculating MRR, it is important to put treatments in order of total costs by summing the net benefit, fixed and variable costs of the two crops from the lowest to the highest cost followed by dominance analysis and the treatment with higher variable cost but with lowest net benefit than the treatment before it is called dominated (CIMMYT, 1988) and the dominated treatments were excluded from the next step of economic analysis (marginal rate of return).

8. Data Analysis

Data entry and processing was carried out using Microsoft excel (MS- Excel, 2010) and all the data collected were subjected to analysis of variance (ANOVA) using SAS version 9.2 (SAS Institute Inc., 2008). Whenever the ANOVA indicated the presence of significant variations between treatments, mean separation was done using least significant difference (LSD) test at 1% and 5% probability level to indicate the minimum difference between mean values under comparison for the variation of the treatment to be significant or not.

RESULTS AND DISCUSSION

Phenology and Growth Response of Sorghum

1. 50% Heading and 90% Maturity

The analysis of variance showed that days to heading and maturity of sorghum were not significantly (P>0.05) influenced by the cropping system, main effect and interaction effects of row arrangement and plant population density (Appendix Table 1). Similarly, Demesew (2002), Dechasa (2005), Jibril *et al.* (2015), Belistie, (2016), Addisu and Seltene (2016), Degu *et al.* (2022), and Wondimkun (2022) reported that days to maturity of maize from maize-common bean intercropping were not affected by component planting densities.

2. Plant height

The analysis of variance (ANOVA) showed that both main and interaction effects of row arrangement and plant population densities was significantly (p<0.05) affected plant height of sorghum (Appendix Table 1). The highest (111.57 cm) plant height of sorghum was in 2S:1M and also the highest (112cm) plant height of sorghum was in 50% population density (Table 2). This research result is disagreed with the finding of Degu *et al.* (2022) in sorghum mung bean intercrop. Similarly, Megersa *et al*. (2019) proved that sole grown maize and intercropped maize-soybean was not significantly affected on plant height and also Zeru *et al.* (2019) confirm that plant height of sorghum in sorghum-cowpea intercropped did not differ due to cropping system. But in contrast with Belistie *et al*. (2016), reported that under maize-haricot bean intercropping height of maize was influenced by cropping system that intercropping maize height was increased by 6% as compared to mono cropping. This may be leads to say the variation on population density and row arrangement of mung bean can influence growth of sorghum. The highest (119.4 cm) plant height of sorghum was obtained when mung bean was intercrop with sorghum in 2S:1M within 100% population density of mung bean whole the lowest (97.76 cm) plant height of sorghum was 1S:1M row arrangement within 100 % population density of mung bean (Table 3).

3. Panicle length

The analysis of variance showed that both main and interaction effects of row arrangement and plant population densities was significantly (p<0.05) affect panicle length of sorghum (Appendix Table 1). The highest panicle length of sorghum (21.56) was recorded from 1S:1M row arrangement and 67% population density of mung bean (Table 2). In line with the finding, reported by Berhane *et al*. (2015), Megersa *et al*. (2019), and Zeru *et al*. (2019) reported that panicle length of sorghum was affected by plant population density and its row arrangement. The interaction effect of row arrangement and population density of sorghum mung-bean were significantly (p<0.05) affect panicle length of sorghum (Appendix Table 1). The highest (25.15 cm) panicle length was obtained when mung bean was intercrop with sorghum in 1S:1M within 67% population density of mung and the lowest (16.23 cm) was 2S:1M row arrangement within 100% population density of mung bean (Table 3).

Table 2: Main effect of row arrangement and population density of sorghum mung bean inter crop on growth and phenology of sorghum

RA	DsH(no)	DsM (no)	Ph(cm)	Pl (cm)
1S:1M	66.11	126.22	110.33[a]	21.56[a]
2S:1M	64.11	124.78	111.87[a]	19.1[b]
3S:1M	64.11	123.00	107.39[b]	18.41[b]
P (0.05)	NS	Ns	**	**
PD				
50%	63.11	124.3	112.7[a]	18.2[b]
67%	65.44	124.44	108.86[b]	21.3[a]
100%	65.77	125.22	108.03[b]	18.9[b]
RA XPD	Ns	Ns	**	**
P (0.05)	Ns	Ns	**	**
C.V (%)	4.14	2.24	2.08	5.17

Where, DsM, days to heading, DsM, days to maturity, Ph, plant height, Pl, panicle length, PD, population density, RA, row arrangement, PD RA, interaction effect of plant population density of mung bean and its row arrangement, sig, significance at5 % and 1 % level of probability and means within the same column no letters of each factor do not statistically differ at P (0.05). Ns, non- significance, ** significance at 1%*

Table 3: Interaction effect of row arrangement and population density of sorghum mung bean inter crop on growth and phenology of sorghum

Combination	DsH (no)	DsM (no)	Ph (cm)	Pl (cm)
1:1 × 50%	62.33	124.33	116.88[abc]	19.23[cd]
1:1 × 67%	63.63	123.66	115.36[b]	25.15[a]
1:1 × 100%	66.66	124.33	97.76[e]	20.3[bc]
2:1 × 50%	64.00	122.33	118.09[ab]	19.3[cd]
2:1 × 67%	68.00	124.66	98.17[e]	21.76[b]
2:1 × 100%	65.00	123.33	119.4[a]	16.23[e]
3:1 × 50%	63.00	126.00	103.16[d]	17.93[de]
3:1 × 67%	64.12	127.00	113.05	17.12[e]
3:1 × 100%	64.6	125.66	105.96[d]	18.60[ab]
CV (%)	4.14	2.24	2.08	5.17
P(0.05)	Ns	Ns	**	**

*Where, DsM, days to heading, DsM, days to maturity, Ph, plant height, Pl, panicle length, p(0.05), significance at 5% and 1% level of probability and means within the same column no letters of each factor do not statistically differ at P (0.05), Ns, non-significance difference and *, significance at 5%,**significance at 1% level of probability*

3. Yield Components and Yield of Sorghum

3.1. Thousand Kernel weight

The analyses of variance on 1000 seed kernel weight shows a non- significance (p > 0.05) effect on the main and interaction effects of row arrangement and plant population densities (Appendix Table 1) and cropping system did not affect 1000 kernel weight of sorghum. Similar with the current finding different scholar for example Degu *et al*. (2022), Enatalem *et al.* (2021), Yayeh *et al.* (2021), Sarlak *et al.* (2008), and Murad and Mohammad (2014) indicated that thousand kernel weight was not affected by intercropping of different cereal-pules, cereals-oil intercrop. But in contrasting to this finding, Zeru *et al.* (2019) reported that 1000 kernel of sorghum were significantly affected due to row arrangement and plant population of the component crop and highly significantly variation due to cropping system.

3.2. Above Ground Biomass

The analyses of variance shows that above ground dry biomass of sorghum was significantly ($P < 0.05$) affected by row arrangement, population density and by their interaction (Appendix Table1). Maximum (65.23 t ha^{-1}) above ground dry biomass was obtained when sorghum was inter crop with mung bean in 3:1 row arrangement and the lowest (59.16 tha^{-1}) dry above ground biomass when sorghum was intercropped with mung bean in 1:1 row arrangement. Besides to this, the heights (64.7407 t ha^{-1}) and the lowest (60.474 t ha^{-1}) above ground dry biomass of sorghum was in 50% and 100% population density of mung bean inter cropped with sorghum (Table 4). Also above ground dry biomass was affected by cropping system and the heights dry biomass was in sole cropping than inter cropping (Table 4). Higher biomass of sorghum (6474.03 kg ha^{-1}) was produced from sole cropping sorghum than that of intercropped with mung bean (59.52 tha^{-1}). This is might be the competition on the available limited growth resources by the intercropped than the sole crop. In line with this funding's, Belsti *et al.* (2016) found 9.3% biomass yield reduction due to intercropping in maize/ haricot bean intercropping

Interaction of row arrangement and plant population density had significant ($P<0.05$) effect on sorghum above ground dry biomass (Appendix Table 1) and the highest (71.704 tha^{-1}) and the lowest (59.852 tha^{-1}) was in 2S:1M × 67% and 3S:1M × 50% (Table 7). In line with this result, Belistie (2016) reported significant higher maize stalk yield for sole crop compared with different mixed cropping treatments. In line with this research result, Megersa *et al.* (2019), and Zeru *et al.* (2019) also reported that above ground dry biomass yield per hectare was highly significantly ($P < 0.01$) affected by the main effects of row arrangement and population density. Similarly, Enatalem *et al.* (2021) also reported that higher above ground biomass were recorded by sole cropping than the inter crop on maize-mung bean inter cropping.

3.3. Grain Yield

Analysis of variance showed that cropping system, the main effects of row arrangement, plant population density and the interaction effect of row arrangement and plant population density had highly significant ($P < 0.01$) effect on grain yield of sorghum when inter cropped with different plant population density of mung bean (Appendix Table 1). Maximum grain yield of sorghum (2920.18 kg ha^{-1}) was achieved at 67% of mung bean population density and the minimum (2637.72 and 2519.87 kg ha^{-1}) was in 100% and 50% population densities respectively (Table 6). This may be due to high in plant population and competition effect as well as due to low in plant population densities as comparing with 67% population density. Similarly, Zeru *et al.* (2019) reported that grain yield of sorghum were affected by cowpea population density. However Tamado and Eshetu (2000) reported that population density had no significant effect on sorghum yield in a sorghum-bean intercropping system.

The analysis of variance showed that significant ($P < 0.01$) effect on sorghum yield when inter cropped with mung bean in different row arrangement (Appendix Table 1). The highest grain yield of sorghum was obtained in 3S:1M (2909.25 kg ha^{-1}) while the lowest grain yield was obtained in 2S:1M (2627.32 kg ha^{-1}) and in 1S:1M (2647.23 kg ha^{-1}) sorghum mung bean row arrangement (Table 4). Similarly, wondimkun (2022) reported that grain yield of maize significantly affected by different row arrangement of the component crop in sorghum mung bean inter crop. Mogiso and Nazib (2020) reported that yield of maize was affected by different row arrangement in maize-common bean inter crop. Habtamu and Tadele (2021) also reported that yield of sorghum were significantly affected by different row arrangement in sorghum-haricot-bean and sorghum-cowpea intercropping. Yayeh (2015) reported intercropping maize-potato in different spatial row arrangement significantly affect potato tuber yield. Similarly, Zeru *et al.* (2019) and Flagot *et al.* (2020), reported that grain yield of maize and sorghum were significantly altered by the difference due to row arrangement and the maximum grain yield of maize were harvested in 1:1 of maize haricot bean inter crop ratio. But this result is disagreed with the findings of Kinde *et al.* (2015) who reported that a non-significant effect of sorghum yield when inter crop with cowpea and soybean in different row arrangement. Also in contrast to this research finding, Gashaw *et al.* (2020) reported that yield of maize were not significantly affected by the row arrangement variation. In this research findings, cropping system showed a significant ($P < 0.01$) effect on grain yield of sorghum (Table 4). The maximum grain yield (3027.83 kg ha^{-1}) was obtained from sole cropping system of sorghum while the lowest grain yield (2649.52 kg ha^{-1}) was achieved from intercropped sorghum. In argument with this result, Other research findings reported by Ijoyaha and Fanen (2012) in maize soya bean, Jibril *et al.* (2015), Yayeh (2015) on Maize -Potato inter crop, Zeru *et al.* (2019) in sorghum-cowpea inter crop; Mogiso and Nazib (2020) on common bean-maize, Habtamu and Tadele (2021) in sorghum haricot bean inter crop, reported that maximum yield were achieved when planting each alone than mixing.

The analysis of variance also shows a significant interaction effect of row arrangement and population density on grain yield of sorghum (Appendix Table 1). The highest grain yield (3030.93 kg ha^{-1}) of sorghum was obtained from the interaction of 2:1 row arrangement of sorghum mung bean with plant population density of 67% and the lowest grain yield of sorghum (2178.88 kg $ha^{-1)}$ was obtained from the interaction of 1:1 row arrangement of sorghum mung bean with 100 % plant population density of mung bean (Table 5). In line with Zeru *et al*. (2019) reported that interaction of row arrangement and population density of cowpea significantly affect grain yield of sorghum. Yield reduction of sorghum was happened when inter cropped sorghum with mung bean in different row arrangement and other reports that maize-soybean intercropping significantly reduced maize grain yield by over sole maize cropping. Due to this, 12.5% yield reduction of sorghum were occurred due to inter cropping of sorghum in mung bean with different row arrangement and plant population density.

Similarly, 9.5% yield reduction of maize were reported by Getachew *et al.* (2013) under maize-bean intercropping compared to sole planting of maize. This may be due to associated with intera specific competition between the intercrop components for growth resources (light, water, nutrients *etc.*) and the competition may be high because of the highest in plant population density and the more the row arrangement of the component crop.

3.4. Harvest Index of sorghum

It is the physiological efficiency and ability of a crop plant for converting the total dry matter into economic yield. Harvest index, which is the ratio of grain yield to dry biomass yield showed statistically a significant ($P<0.05$) difference due to row arrangement and the interaction between row arrangement and plant population density planting density (Appendix Table 1) however, plant population density did not affect harvest index of sorghum. Higher harvest index (46.23%) was recorded for 3S:1M row arrangement of mung bean (Table 4) and lower harvest index of sorghum (40.06) was received under 2S:1M row arrangement of mung bean respectively. Its highest and lowest value might be due to inter specific competition for growth resources, i.e., moisture, nutrients and light and may be due to the highest in plant population due to increasing in rows per hectare base. In contrasting with other findings, Murad and Mohammad (2014); Gashaw *et al.* (2020) and Enatalem *et al.* (2021) reported that harvest index is not significantly affected by row arrangement in maize mung bean, sunflower-mung bean and cluster bean-sesame inter crop. The present result dis agreed with that reported by Megersa *et al.* (2019) reported that harvest index showed statistically a significant difference due to planting density and he reported that the highest harvest index (41.35%) was obtained from 25% planting density of soybean and the lowest harvest index (35.8%) was from 75% soybean planting density. High harvest index indicates the presence of good partitioning of dry matter to grain yield. Although the results of the study showed cropping system influence on harvest index was not marked statistically.

The analysis of variance also shows significant (p<0.05) effect on harvest index of sorghum in the interaction of row arrangement and plant population density of mung bean (Appendix Table 1). The highest harvest and the lowest harvest index of sorghum (49.15%) and (37.32%) was obtained in the interaction of 1S:1M × 50% and in 2S:1M × 50% (Table 5).

Table 4: Main effect of row arrangement, plant population density and cropping system on yield components and yield of sorghum

Row arrangement	BM (t ha^{-1})	TSW(gr)	GY(kg ha^{-1})	HI (%)
1S:1M	59.52^{b}	30.56	2649.23^{b}	44.37^{a}
2S:1M	62.64^{b}	29.80	2627.32^{b}	40.06^{b}
3S:1M	65.23^{a}	28.83	2909.25^{a}	46.23^{a}
P (0.05)	**	Ns	**	**
Population density				
50 %	64.74	30.41	2637.72^{b}	42.12
67 %	60.6	29.50	2920.18^{a}	44.44
100 %	60.5	29.28	2519.87^{b}	46.50
P (0.05)	**	Ns	**	Ns
C.V (%)	3.27	6.4	4.6	5.94
PPD X RA	**	Ns	**	**
Cropping system				
Sole sorghum	64.8^{a}	30.67	3027.83^{a}	45.50
Intercrop sorghum	59.54^{b}	29.44	2649.52^{b}	44.37
p (0.05)	**	Ns	**	Ns
C.V (%)	11.36	6.24	8.36	5.41

Where, SW, thousand seed weight, BM, above ground biomass, GY, grain yield, HI, harvest index and PPD RA, interaction effect of plant population density of mung bean and its row arrangement, sig, significance and means within the same column followed by the same letter or by no letters of each factor do not statistically differ at P (0.05), Ns, non-significance and ** significance at 1 % level of probability.*

Table 5: Interaction effect Sorghum-mung bean intercropping on yield and yield related parameters of sorghum

Combination	BM (t ha^{-1})	TSW (gr)	GY (kg ha^{-1})	HI (%)
1:1 × 50 %	61.462^{bc}	31.51	3020.45^{a}	49.15^{a}
1:1 × 67 %	61.9561^{bc}	29.50	2749.51^{abc}	44.41^{abc}
1:1 × 100 %	55.1413^{de}	30.67	2178.88^{d}	39.55^{cd}
2:1 × 50 %	71.4023^{a}	29.33	2667.31^{c}	37.32^{d}
2:1 × 67 %	71.7042^{a}	29.33	3030.93^{a}	42.24^{bdc}
2:1 × 100 %	66.4300^{ab}	29.67	2880.41^{abc}	43.84^{abc}
3:1 × 50 %	50.0053^{e}	30.43	2333.52^{d}	46.85^{ab}
3:1 × 67%	64.1281^{bc}	29.00	2980.23^{ab}	46.46^{ab}
3:1 × 100 %	59.8524^{cd}	28.16	2716.43^{cb}	45.38^{abc}
CV (%)	3.27	6.42	4.66	5.94
P (0.05)	**	Ns	**	**

*Where, TSW, thousand seed weight, BM, above ground biomass, GY, grain yield, HI harvest index, and Values within a column followed by the same letter are not significantly different at 5%, Ns, non- significance and ** significance at 1% level of probability*

4. Phenology and growth parameters of mung bean

4.1. Days to 50% Flowering and 90% physiological Maturity

Analysis of variance showed that plant population density, row arrangement, cropping system and interaction of row arrangement and population density was not significantly (P >0.05) affect the days to 50% flowering and days to 90% maturity of mung bean (Appendix Table 2). Similarly, Megersa *et al.* (2019) in maize-soybean inter crop, Nuru and Tarikua (2021), Zeru *et al.* (2019) in sorghum-cowpea and Degu *et al.* (2022) in sorghum-mung bean intercrop, reported that days to 50% flowering and 90% maturity were not significantly affected by cropping system and different row arrangement and population density. But this research findings result is dis argued with Enatalem *et al.* (2021) that cropping system have a significant effect on days to flowering and days to maturity of mung bean in mung bean maize intercrop. A non- significant difference among the growth and phenological parameters of mung bean under mung bean sorghum inter crop is may be due the different in resource utilization between the inter crop species and the two crops may not sharing nutrient like light soil, water at critical growth period of the two crops

4.2. Plant Height

Results of the analysis of variance showed that mung bean plant height was not significantly (P > 0.05) affected by row arrangement and plant population density (Appendix, Table 2) and also by density or cropping system. In line with Mitiku and Getachew (2017) Asaye *et al.* (2018), and Megersa *et al.* (2019) reported that plant height not affected by different row arrangement and population density. But this result is disagreed with Mohammad (2014), Enatalem *et al.* (2021), and Degu *et al.* (2022)

who reported that sorghum mung bean intercrop significantly effect on, plant height by the different row arrangement of sorghum mung bean intercrop.

The analysis of variance regarding to the interaction of row arrangement and population density, shows a significance effect on plant height of mung bean in mung bean sorghum inter crop (Appendix Table 2) and the highest (59.26 cm) and the lowest (47.43 cm) plant height of mung bean was happened when mung bean inter crop with sorghum in 2S:1M × 50% and 3S:1M × 50%. A non- significant difference among the growth and phenological parameters of mung bean under mung bean sorghum intercrop is may be due the different in resource utilization between the intercrop species and the two crops may not sharing nutrient like light, soil, and water at critical growth period of the two crops.

5. Yield Components and Grain Yield of mung bean

5.1. Number of Pods per Plant

Analysis of variance showed that, the main effects of row arrangement and plant population density and cropping system showed a non- significant (P>0.05) effect on pod number per plant of mung bean (Appendix Table 2). However, the interaction effect of the two was affected pod per plant significantly. Similarly Murad and Mohammad (2014) also reported that number of pods per plant were not significantly differed by row arrangement but affected by cropping system. In contrast to this study Degu *et al.*(2022) in sorghum mung bean intercrop, number of pods per plant were significantly affected by row arrangement and cropping system. Mitiku and Getachew (2017) reported that number of pods per plant were significantly affected by planting density but not affected by cropping system. In contrast with this findings, Megersa *et al.* (2019) reported that number of pod per plant were significantly affected by planting density in maize soybean intercrop. In terms of interaction effect of row arrangement and population density, the analysis of variance showed a significances effect on number of pod per plant (Appendix Table 2). The maximum (40.3) and the minimum (24.7) number of pods per plant was found in 1S:1M × 100% and 1S:1M × 50% row arrangement and population density of mung bean (Table 8).

5.2. Number of seeds per pod

Number of seeds per pod was not significantly (P>0.05) affected by main and interaction effect of plant population and row arrangement (Appendix Table 2) as well as by cropping system (Table 6). This may be due to the absence of nutrient computation at the critical period of the two intercrop species because of the dissimilarity nature of the two crops. This result was in agreement with the result reported by Murad and Mohammad (2014), Nuru and Tarikua (2021), and Degu *et al*. (2022), who reported that number of seed per pod were not significantly affected by row arrangement and population density in sorghum-mung bean and in maize common bean inter crop. Megersa *et al.* (2019) also reported that number of seed per pod were not significantly affected by plant population density and variety in maize-soybean intercrop. But in contrast to this study, Jibril *et al.* (2015) revealed that seed of common bean per pod were significantly affected by cropping system and plant population.

5.3. Thousand Seed Weight

Thousand seed weight of mung bean in the main factors was significantly ($p < 0.05$) affected by main and interaction effect of plant population and row arrangement (Appendix Table 2) but not affected by cropping system (Table 7). The highest (58.75 gr) 1000 seed weight of mung bean was found in 2S:1M row arrangement of sorghum mung bean inter crop whole the lowest (54.1 gr) was in 1S:1M (Table 6). In line with this study, wondimkun (2022) reported that thousand seed weight was significantly affected by spatial row arrangement of mung bean. The highest (58.16 gr) and the lowest (53.85 gr) 1000 seed weight of mung bean was when mung bean intercrop with sorghum with a population density of 67% and 100% respectively. (Table 6). In contrasting to this, Mitiku and Getachew (2017) also reported that thousand seed weight common bean were not significantly affected by plant population density and this may be due to lowest intra-row competition in mung bean crops that helps crops to grow well and accessed resources enough for grain filling. The analysis of variance revealed that the interaction of row arrangement and population density significantly affect 1000 seed weight of mung bean and the highest (61 gr) and the lowest (47.7 gr) 1000 seed of mung bean was when mung bean inter crop with sorghum in 2S; 1m × 50% and 3S:1M × 50 % (Table 8).

5.4. Above Ground Biomass

Above ground biomass shows a high significant effect ($p < 0.01$) on main effects of row arrangement and plant population density of mung bean (Appendix Table 2). The highest above ground biomass (27.7090 tha^{-1}) was obtained from 1:1 row arrangement of sorghum- mung bean inter crop and the lowest (12.0491 tha^{-1}) above ground biomass was occurred in 3:1 ratio of sorghum mung bean inter crop (Table 6). Similarly, Muktar *et al.* (2019) also reported mung bean-sugarcane intercrop was significantly affected on above ground biomass of mung bean by the presence of different row arrangement and similarly, Debela *et al.* (2022), reported that above ground biomass was highly significantly affected due to row arrangement variation in wheat-faba bean inter- crop. The highest above ground biomass (21.7085 tha^{-1}) were obtained from 100% plant population density of mung bean and the lowest above ground biomass (12.05 tha^{-1}) were record in 50% plant population density of mung bean (Table 6). Also Megersa *et al.* (2019) reported that above ground biomass of soybean were significantly differed in plant population density in maize-soybean inter-crop and maximum above ground biomass achieved in 75% soybean plant population density. Other research finding reported by Mitiku and Getachew (2017) dry above ground biomass of common bean was significantly affected by plant population density and the highest dry above ground biomass were achieved with 75% plant population density of common bean in common bean- maize inter- crop.

The analysis of variance also shows an interaction effect ($p<0.05$) on above ground biomass of mung bean (Appendix Table 2) and the maximum (30.12 tha^{-1}) above ground biomass of mung bean was in 1S:1M × 100% row arrangement and population density (Table 8). Similarly, Wondimkun (2022) reported that above ground biomass were significantly affected by both the interaction of row arrangement and plant population density and he reported that the maximum above ground biomass was recorded from 75% population density and 1:3 maize- mung bean inter- crop row arrangement. In this research findings, the highest above ground biomass (30.2 tha^{-1}) was recorded in the interaction of 1S:1M row arrangement with 100% plant population density whereas the lowest above ground biomass of mung bean (10.67 tha^{-1}) was obtained in 3S:1M row arrangement with 50% plant population density of mung bean (Table 8). This significant effect is may either due to high nutrient competition in their growth period or due to low in plant population density of the component crop because that higher plant population density of mung bean resulted in greater above ground biomass yield than the lower plant population density of mung bean.

The above ground biomass of mung bean in sole planting was significantly higher than the intercropped. The highest above ground biomass were obtained from the sole cropping (46.22 t ha^{-1}) whole the lowest was registered on the inter crop (36.7 tha^{-1}) (Table 7). Thus, the sole crop of mung bean was higher than the intercrop by 20.69%, which might be because of intra specific competition on the available limited growth resources by the intercropped than the sole crop. Similar to this study, Murad and Mohammad (2014) in sunflower mung bean inter crop; Jibril *et al.* (2015) in maize common bean inter crop; Megersa *et al.* (2019) in maize soya bean inter crop; Enatalem *et al. (*2021), in maize- mung bean inter crop, and Debela *et al.* (2022) in wheat-faba bean inter crop confirmed that highest above ground biomass were obtained in sole cropping system than inter- crop.

5.5. Seed Yield of Mung Bean

The statistical analysis of variance in sorghum mung bean inter crop indicated that yield of mung bean grain yield was highly significant ($P<0.01$) variation with respect to row arrangement and significantly varied ($p<0.05$) on plant population density and highly significant ($P < 0.01$) variation with their interaction (row arrangement and plant population density) (Appendix Table 2). The highest grain yield (502.42 kg ha^{-1}) was obtained from the intercropped row arrangement of 1:1 sorghum-mung bean intercrop while the lowest seed yield (220.54 kg ha^{-1}) were obtained in 3:1 sorghum-mung bean inter crop row arrangement pattern (Table 6). Besides this, maximum grain yield of mung bean (378.07 kg ha^{-1}) were obtained in 100% plant population density while the lowest grain yield (308.86 kg ha^{-1})

were obtained from 50% plant population density (Table 6). The increased seed yield with the increase in plant population of mung bean which could be the result of more plant established under the intercropping and which could be due to higher number of plants per unit area due to this, grain yield of mung bean increase as plant population increase. Similar to this research finding reported by Wondimkun (2022) that seed yield of mung bean were significantly affected by plant population density and the maximum grain yield was obtained from 100% population density and in contrast to this study he reported that a non- significance difference of mung bean seed yield in cropping pattern.

Table 6: Main effect of row arrangement and population density of sorghum mung bean inter crop on mung bean seed yield and seed yield related traits

Row arrangement	NPP (no)	NSPP (no)	TSW (gr)	BM (kg ha^{-1})	GY (kg ha^{-1})	HI (%)
1S:1M	30.66	11.44	54.10[b]	21.71[a]	502.42[a]	24.021[a]
2S:1M	28.94	11.5	58.75[a]	12.37[b]	310.72[b]	25.482[a]
3S:1M	30.58	11.3	55.23[b]	11.21[c]	220.54[c]	20.622[b]
P (0.05)	Ns	Ns	**	**	**	**
Population density						
50 %	26.92[b]	11.46	56.06[ab]	13.72[b]	308.93[c]	22.196[b]
67 %	29.68[b]	11.14	58.16[a]	12.89[b]	346.66[b]	26.832[a]
100 %	33.53[a]	11.63	53.85[b]	18.65[a]	378.07[a]	21.098[b]
P(0.05)	**	Ns	**	**	**	**
RA × PD	**	Ns	**	**	**	**
C.V (%)	9.81	6.79	5.09	6.13	5.38	12.02

Note: *S, sorghum, M, mung bean, NPP, number pod per plant, NSpp, number seed per pod, Tsw, 1000 seed weight, BM, above ground bio mass, GY, grain yield, HI, harvest index, RAX PD, interaction of row arrangement with population density, C.V, Coefficient of variance; P (0.05), least significant difference at p<5%; Means in a column followed by the same letters or column's haven't any letters are not significant different at p<5% level of significant, Ns, non- significance and ** significance at 1% level of probability.*

Also, Megersa *et al.* (2019) confirmed that yield of soybean were significantly affected by plant population difference and maximum grain yield of soybean was obtained with 75 % plant population density in soybean -maize intercrop. Teshome *et al.* (2015) also confirmed that grain yield of soybean significantly affected due to the variation in plant population density in soybean-maize inter- crop. Maximum grain yield of soybean was reported in 75 % soybean plant population density followed by 50% (Teshome *et al.* 2015). Degu *et al.* (2022) on sorghum-mung bean inter crop and Debela *et al.* (2022) in wheat-faba bean inter crop reported that grain yield were significantly affected due to planting pattern (row arrangement) difference. But this research finding disagreed with Murad and Mohammad (2014) reported that yield of mung bean were not significantly affected by row arrangement variation in sunflower -mung bean inter- crop.

Mung bean seed yield was highly significantly affected by the interaction effect of row arrangements and population density (Appendix Table 2). The maximum seed yield of mung bean (626.37 kg ha^{-1}) were recorded with the interaction of 1S:1M planting patter (row arrangement) with 100% plant population density of mung bean (Table 8) and the lowest seed yield of mung bean (149.63 kg ha^{-1}) were obtained in the interaction of 3:1 sorghum- mung bean planting pattern with 50% plant population density of mung bean. The low seed yield of mung bean in this experiment is may be due to the lowest plant densities and lower in row number as comparing with other treatments. Similarly, Zeru *et al.* (2019) in sorghum-cowpea inter crop reported that the maximum seed yield of cowpea were obtained from interaction effect of 1:1 sorghum- cowpea row configuration.

Cropping system also showed highly significant ($p < 0.01$) effect on seed yield of mung bean and the highest grain yield of mung bean (1258.37 kg ha^{-1}) was recorded from the sole cropping while the lowest grain yield (342.25 kg ha^{-1}) was obtained in sorghum-mung bean inter-cropped (Table 8). Up to 72.81% yield reduction of mung bean were made due to intercrop with sorghum. Reasons of reduction in seed yield of mung bean might be due to adverse shading effect sorghum plants which depressed growth and yield attributes of mung bean or may be due to growth resource sharing during the growth periods of the two crop species more in the critical growth or either the lower mung bean plant population density in intercropping than sole cropping. Similarly, Enatalem *et al.* (2021) reports that seed yield reduction of mung bean in maize-mung bean intercrop were made by 60% due to intercropping. According to Saleem *et al.* (2015), in maize-mung bean intercropping, intercropping reduced the mung bean yield by 28% compared to mung bean solitary cropping. In agreement to this study, Teshome *et al.* (2015), Megersa *et al.* (2019), Arshad *et al*. (2020), Enatalem *et al.* (2021), and Debela *et al.* (2022) reported that maximum seed yield were obtained in sole cropping system than the inter crop.

5.6. Harvest Index

The analysis of variance showed the main effect of row arrangement and population density the interaction of plant population density and row arrangement was show a significant ($P < 0.05$) effect on harvest index of mung bean (Appendix Table 2). Maximum harvest index (26.83%) was obtained from 67% plant population density while the lowest (21.09%) was recorded from 100% plant population density of mung bean (Table 6). This result is in line with Teshome *et al.* (2015) who reported that the highest harvest index was obtained at 25 % than 50% and 75% plant population density in soybean-maize inter crop. Negasa *et al.* (2021) also reported a significant effect on harvest index in plant population density difference on soybean-maize inter crop and he got maximum highest harvest index of soybean in 50% (28.33%). Megersa *et al.* (2019) also reported harvest index of soybean was affected by population density in soybean-maize intercrop and he recorded maximum harvest index on 50% plant population density even if it vary based on the variety he used. But this result is disagreed with Mitiku and Getachew (2017) that harvest index of common bean not significantly affected by plant population density of common bean that changed from 25% to 75% in common bean rice inter- crop. Besides to this harvest index of mung bean was significantly affecting due to the variation in row arrangement and the maximum (25.48 %) harvest index was 2S:1M and the lowest (20.62%) in 3S:1M respectively (Table 6).

Also the highest harvest index of mung bean (29.87%) was obtained from the interaction of 50% mung bean plant population density with 2S:1M row arrangement while the lowest harvest index (14.02%) was obtained from the interaction of 50% plant population density of mung bean with 3S:1M row arrangement (Table 8). The highest harvest index was obtained from at lowest population density that might be there was low competition in lowest population density and the efficiency of converting biological yield to the economic yield may be high. Harvest index of mung bean was not affected by cropping system (Table 8). Similar to this study, other research findings done by Megersa *et al.* (2019), Muktar *et al.* (2019), and Negasa *et al.* (2021) reported that harvest index in an intercrop did not significantly affected by cropping system.

Table 7: Effect of cropping system on seed yield and seed yield related of mung bean

Cropping System	NPP (no)	NSPP (no)	BM (tha^{-1})	TSW (gr)	SY (kg ha^{-1})	HI (%)
Sole cropping	31.3	12.26	46.2223^{a}	53.84	1258.37^{a}	26.45
Inter- crop	30.7	11.94	36.6552^{b}	52.45	342.25^{b}	25.68
P (0.05)	Ns	Ns	**	Ns	**	Ns
C.V (%)	3.71	2.54	11.52	4.68	6.89	9.45

*Where, Npp, number of pod per plant, NSPP, number of seed per pod, TSW, 1000 seed weight, BM, above ground bio mass, SY, Seed yield, HI, harvest index, CV, Coefficient of variance; P (0.05) least significant difference at p <5 %; Means in a column followed by the same letters are not significant different at p <5 % level of significant, Ns, non- significance and ** significance at 1% level of probability.*

Table 8: Interaction effect of population density and row arrangements of sorghum mung bean intercrop on mung seed yield and yield related

Treatment combination	NPP (no)	SPP (no)	BM (t ha^{-1})	TSW (gr)	SY (kg ha^{-1})	HI (%)
1:1 × 50%	24.7^{d}	11.7	1955.6^{b}	58.9^{ab}	441.78^{b}	22.68^{cb}
1:1 × 67%	27^{d}	11.26	1540.7^{cb}	56.8^{ab}	439.11^{b}	28.58^{ab}
1:1 × 100%	40.3^{a}	11.36	3016.3^{a}	46.6^{c}	626.37^{a}	20.79^{cd}
2:1 × 50%	28^{cd}	11.4	1125.9^{cd}	61.5^{a}	335.41^{c}	29.87^{a}
2:1 × 67%	26.2^{d}	11.0	1303.7^{cd}	59.9^{a}	306.67^{cd}	23.77^{abc}
2:1 × 100%	32^{bc}	12.0	1481.5^{cd}	54.7^{b}	290.07^{d}	20.13^{cd}
3:1 × 50%	28^{cd}	11.3	1066.7^{d}	47.7^{c}	149.63^{f}	14.02^{d}
3:1 × 67%	35.8^{ab}	11.13	1422.2^{cd}	57.8^{ab}	294.22^{d}	23.13^{abc}
3:1 × 100%	27.8^{cd}	11.4	1125.9^{cd}	60.2^{a}	217.78^{e}	19.70^{cd}
C.V (%)	9.81	6.79	5.09	6.13	5.38	12.02
P (0.05)	**	Ns	**	**	**	**

Note: *PPP, pod per plant, Spp, seed per pod, Tsw, 1000 seed weight, BM, above ground bio mass, GY, grain yield, HI, harvest index, C.V, Coefficient of variance; P (0.05), least significant difference at p<5%; Means in a column followed by the same letters or no letters are not significant different at p<5% level of significant, Ns, non-significance and ** significance at 1% level of probability.*

6. System productivity of sorghum and mung Bean in sorghum -mung bean intercropping

6.1. Land Equivalent Ratio

LER is an effective and widely used index for comparing the productivity of intercropping systems with sole cropping and any value greater than 1.0 indicates a yield advantage for intercrop. In this experimental research findings, Partial LER of sorghum was significantly (P<0.01) affected by row arrangement, population density and their interaction (Appendix Table 3). The result was dis confirmed by Jibril *et al*. (2015) in maize and haricot bean intercropping study. The highest partial LER of sorghum (0.9433) was found at 2S:1M row arrangement (Table 9). The reason was probably due to computation effect because of exploit available resources efficiently compared to 1S:1M and 3S:1M.

Regarding to plant population densities, PLER sorghum was significantly (p<0.01) affected by plant population densities and the heights (0.9644) PLER sorghum was in 67% population densities. Also the partial LER of mung bean, was significantly (P < 0.01) affected by row arrangement, plant population densities and their interactions. The highest (0.4) Partial land equivalent ratio of mung bean was achieved in 1S:1M row arrangement and the lowest (0.1767) PLER mung bean was in 3S:1M row arrangement. This may be due to the highest rows and the lower number of rows in mung bean when intercropped with sorghum. Also the highest (0.3) PLER of mung bean was by population density of 100 % and the lowest (0.2467) was in 50 % plant population densities of mung bean (Table 9). This was probably due to in the higher population per unit of area with that of 67% and 50%.

This finding results showed a significance interaction effect (P<0.01) on the partial LER of sorghum and mung bean. The PLER sorghum were higher than 0.50 for all intercrops which indicates that there is an advantage of mung bean inter crop for sorghum production (Appendix Table 3). The partial land equivalent ratio of sorghum was between (- 0.72 to 1.001) and in mung bean, the partial land equivalent ratio were ranged from 0.12 to 0.4967 (Table 10). It indicated that the yield of inter cropped sorghum were higher than the mung bean. As we comparing the two partial LER values of the two combined crops, partial LER of sorghum was higher than partial LER of mung bean in the system. Thus, the results indicated that sorghum was the major contributor to the mixture yield. In this research finding, the total LER was higher than unity except the treatment in the combination of 3S:1M sorghum mung bean arrangement with 50% plant population density of mung bean. It indicated that inter cropping of sorghum -mung bean in the study area is more beneficiary than cropping alone.

the total value of land equivalent ratio was greater than one except in 3S:1M × 50% and this indicates that in most of the treatment combination inter crop sorghum with mung bean was advantages and the highest total LER (1.35) was obtained in 1S:1M sorghum mung bean row arrangement with 50 % plant population density of mung bean and the lowest total LER (0.89) was obtained in 3S:1M row arrangement with 50% plant population density of mung bean. (Table 10). This means that 35% additional land were required to produce the same yield as intercropped (to equal with the yield of intercropping system) and the farmers save 35 % land because of inter cropping. Other study done by Ijoyah and Fanen (2012) 46.2% land were saved due to intercropping in maize-soybean intercrop. It may be prove that high plant population density negatively affect the overall yield and resulting in LER values less than one in inter cropping system. Ashenafi (2016), and Alemu (2017) confirming that the values above unity in most systems indicated complementarities in resource utilization by the component crops. In line with this finding, Ashenafi (2016) reported that maximum land equivalent ratio was recorded on 1:1 in maize haricot bean row planting pattern. Yayeh (2015) also reported that the highest total LER were obtained in 1:1 row arrangement in maize-potato inter crop and also Mogiso and Nazib (2020) reported that the highest total LER were in 1:1 maize common bean row arrangement. Regarding to plant population density, in line with this findings, Jibril (2015) reported that planting maize with the lowest plant population density of common bean is advantages in maize common bean inter crop.

Also in line with this research result, Zeru *et al*. (2019), Flagot *et al.* (2020), and Gashaw *et al.* (2020) reported that the highest total LER were obtained in 1: 2 maize-haricot bean inter crop row arrangement. Similarly, Degu *et al.* (2022) reported that the highest total LER were in 1:2 sorghum mung bean row arrangement. Also Mohammad *et al.* (2018) reported that the highest total LER in turmeric-mung bean inter crop when planting in 1:3 row arrangement with 50% plant population density of mung bean. In argument with this finding's, Shaker and

Nasrollahzadeh (2014) reported that total LER were in 1:1 row arrangement of sorghum mung bean intercrop. But regarding to the plant population density, this research finding were contrasting with the findings done by Megersa *et al.* (2020) and Wondimkun (2022) reported that the highest total LER were obtain in 100% plant population density of maize- mung bean maize-soybean and turmeric-mung bean respectively.

6.2. Competitive Ratio (CR)

Competitive ratio (CR) is another way to know the degree with which one crop competes with the intercrop and a simple competitive ratio (CR) is proposed as a measure of intercrop competition, to indicate the number of times by which one component crop is more competitive than the other. The analysis of variance shows that CR of sorghum was significantly affected by row arrangement, plant population densities and their interactions (Appendix Table 3). Maximum (1.1589) CR of sorghum was in 1S:1M row arrangement and the lowest (1.18) was in 3S:1M and regarding to the population densities, the highest (1.488) CR of sorghum was in 67% and the lowest (1.29) CR of sorghum in 50% plant population densities of mung bean (Table 9).

Table 9: Main Effect of sorghum mung bean row arrangement and population density on land equivalent ratio, competitive ratio and area time equivalent

RA	PLERS	PLERM	TLER	CRS	CRM	ATER
1S:1M	0.8744^b	0.4^a	1.2744^a	1.589^a	0.914^a	1.146^a
2S:1M	0.9433^a	0.2478^b	1.19^b	1.147^b	0.822^b	1.08^b
3S:1M	0.8856^b	0.1767^c	1.06^c	1.18^c	0.7^c	1.03^b
P (0.05)	*	**	**	**	**	**
PD						
50%	0.8833^b	0.2467^c	1.129^b	1.29^b	0.656^c	1.06
67%	0.9644^a	0.2778^b	1.239^a	1.488^a	0.986^a	1.11
100%	0.8556^b	0.3^a	1.156^b	1.407^a	0.792^b	1.08
Sig (0.05)	**	**	**	**	**	Ns
RA*PD	**	**	**	**	**	**
C.V (%)	5.92	7.08	4.8	5.93	8.5	5.51

*Where, RA, row arrangement of mung bean with sorghum, PD, plant population density of mung bean, ARX PPD, interaction effect of row arrangement and population density, PLERS, partial land equivalent ratio of sorghum, PLERM, partial land equivalent ratio of mung bean, TLER, total land equivalent ratio, CRS, competitive ratio of sorghum, CRM, competitive ratio of mung bean, ATER, area time equivalent ratio of the system, Ns, non- significance and ** significance at 1% level of probability.*

Like that of sorghum, CR vale of mung bean was significantly (P<0.01) affected by plant population densities, row arrangement and their interactions (Appendix Table 3). The highest and the lowest (0.914 and 0.7) CR vale of mung bean was in 1S:1M and 3S:1M row arrangement respectively. Also the highest and the lowest (0.986 and 0.656) CR value of mung bean was 67% and 50% population densities respectively (Table 9). According to the interaction result listed on table 10, the highest (1.81) CR value of sorghum was obtained in 67% plant population density of mung bean with 1S:1M row arrangement while the lowest (1.03) was recorded in 50% plant population density of mung bean with 3S:1M row arrangement and the highest CR value of mung bean (1.04) were obtained on 1:1 sorghum mung bean row arrangement with 67% plant population density of mung bean while the lowest CR value of mung bean (0.47) was recorded on 3S:1M row arrangement with 50% plant population density of mung bean. In this experimental research result, the CR value of sorghum was higher than the CR value of mung bean. This indicated that sorghum was more competitive than mung bean in sorghum mung bean inter cropping in the study area.

Similarly with this finding, Ashenafi (2016) reported that maize were more competitive than haricot bean in maize-haricot bean inter crop. Yirsaw *et al.* (2022) reported that *tef* had higher CR value than lupine in tef-lupine inter crop. In addition, Khond *et al.* (2018) reported that maize had high CR value than soybean and cowpea and he concluded that the competitive ability of maize were higher than legumes. Similarly Mohammad *et al.* (2018) reported in turmeric-mung bean inter crop, turmeric were had higher CR value than mung bean in 1:1 turmeric-mung bean inter crop with 33% mung bean plant population density of mung bean and turmeric were more competitive than mung bean. Similarly, Murad and Mohammad (2014) reported that CR value of sunflower is higher than mung bean in mung bean- sunflower intercrop and they conclude that sunflower were more competitive than mung bean. In addition to the authors list above, Zenebe *et al.* (2021) reported that sorghum were more competitive than soybean in sorghum- cowpea inter crop.

6.3. Area time equivalent ratio (ATER)

LER doesn't consider the duration of the crops in the field. Area time equivalent ratio (ATER) provides more realistic comparison of the yield advantage of intercropping over sole cropping in terms of variation in time taken by the component crops of different intercropping system. The analysis of variances indicates that ATER was significantly ($p<0.01$) affected by row arrangement and interaction of row arrangement and population densities but not significantly varied by population densities of mung bean (Appendix Table 3). Higher (1.146) ATER was record in 1S:1M and the lowest (1.03) was achieved in 3S:1M row arrangement of sorghum- mung bean intercrop (Table 9). The interaction result presented in table 15, showed that in all sorghum-mung bean intercropping arrangements expected treatment in 3:1 × 50%, the ATER values were greater than one indicating 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 matured and indicated that sorghum- mung bean inter cropping is more advantages in the test location.

Table 10: Interaction effect of sorghum mung bean row arrangement and population density on land equivalent ratio, competitive ratio and area time equivalent

Ttr. com.	PLER S	PLERM	TLER	CRS	CRM	ATER
1:1 × 50%	0.9967^{ab}	0.3533^{b}	1.35^{a}	1.51^{bc}	0.70^{b}	1.23^{a}
1:1 × 67%	0.9067^{bcd}	0.35^{b}	1.257^{ab}	1.81^{a}	1.04^{a}	1.15^{ab}
1:1 × 100%	0.72^{e}	0.4967^{a}	1.217^{bc}	1.44^{cd}	0.99^{a}	1.06^{bc}
2: 1 × 50%	0.88^{d}	0.2667^{c}	1.147^{cd}	1.33^{de}	0.81^{b}	1.03^{cd}
2:1 × 67%	1.00^{a}	0.2467^{cd}	1.243^{bc}	1.33^{de}	0.97^{a}	1.08^{bc}
2:1 × 100%	0.950^{abcd}	0.23^{d}	1.18^{bc}	1.58^{b}	0.69^{b}	1.13^{abc}
3:1 × 50%	0.7733^{e}	0.12^{f}	0.89^{e}	1.03^{f}	0.47^{c}	0.94^{d}
3:1 × 67%	0.9867^{abc}	0.2367^{cd}	1.216^{bc}	1.31^{de}	0.93^{a}	1.10^{bc}
3:1 × 100%	0.8967^{cd}	0.1733^{e}	1.07^{d}	1.19^{e}	0.69^{b}	1.05^{bc}
P(0.05)	**	**	**	**	**	**
C.V (%)	5.92	7.08	4.8	5.93	8.5	5.51

*Where, Ttr com, treatment combination, PLERS, partial land equivalent ratio of sorghum, PLERM, partial land equivalent ratio of mung bean, TLER, total land equivalent ratio, CRS, competitive ratio of sorghum, CRM, competitive ratio of mung bean, ATER, area time equivalent ratio of the system, Ns, non- significance and ** significance at 1% level of probability.*

The highest ATER value (1.23) is recorded in 1S:1M row arrangement with 50% plant population density while the lowest (0.94) was obtained in 3S:1M row arrangement with 50% plant population density (Table 10). This could be due to the reason that in 1S:1M intercropping arrangement may be compatible and more efficient resource exploitation and greater overall production than remaining intercropping arrangements. ATER was below one in 3S:1M with 50% population density of mung bean inter cropping arrangement and indicated the disadvantage of inter crop in this ratio and density. Similarly to this research results, the highest ATER were reported by Yayeh (2015) in 1:1 maize-potato intercrop. Similarly, Murad and Mohammad (2014) reported that higher ATER in 1:1 sunflower- mung bean inter crop.

6.4. Gross monetary value (GMV)

Gross monetary value (GMV) was calculated as the product of yields of the component crops (kg ha^{-1}) multiplied by their respective unit prices during harvesting time. Besides to LER and other intercropping index, gross monetary value (GMV) and monetary advantage index (MAI) were used to evaluate the economic benefits of inter cropping of sorghum with mung bean in different row arrangement and plant population density of mung bean in terms of increased value per unit area of land. The result of this research finding listed in appendix table 3, GMV of sorghum was significantly ($p<0.01$) affected by row arrangement, population density of mung bean and their interaction. The highest (60049 ETB ha^{-1}) GMV of sorghum was record in 2S:1M and in 3S:1M (56211 ETB ha^{-1}) while the lowest (55641 ETB ha^{-1})) GMV of sorghum was in 1S:1M row arrangement. In the side of population densities, the highest (61324 ETB ha^{-1}) and the lowest (54429 ETB ha^{-1}) GMV of sorghum was in 67% and 100% population density of mung bean. When considering mung bean, the highest (22609 ETB ha^{-1}) GMV of mung bean was when mung bean intercropped in 1S:1M row arrangement with sorghum. While the lowest (9924 ETB ha^{-1}) GMV of mung bean was achieved when mung bean intercropped with sorghum in 3:1 ratio (Table 11). Beside this, the highest and the lowest mung bean GMV (17013 and 13902 ETB ha^{-1}) was record when mung bean planted with sorghum with a plant population densities of 100% and 50% respectively. This finding is in line with Megersa *et al.* (2020).

Like that of GMV, TGMV (total gross monetary value) of the two experimental crops was significantly ($p<0.01$) affected by row arrangement, plant population and their interaction (Appendix Table 3). Maximum (78250 ETB ha^{-1}) TGMV was achieved when sorghum intercrop with mung bean in 1:1 row arrangement and also the highest (76924 ETB ha^{-1}) TGMV of sorghum was when sorghum intercrop with 67% of mung bean population densities (Table 11). The interaction result of this research finding listed in table 12, shows that the total maximum gross monetary value (83309 ETB ha^{-1}) was recorded in 1S:1M row arrangement with 50 % plant population density of mung bean while the lowest total gross monetary value (55737 ETB ha^{-1}) was registered in 3S:1M row arrangement with 50% plant population density of mung bean (Table 12). This may be due to the high plant population density of mung bean per row of sorghum resulted in more competition and reduction in yield. Similarly Mitiku and Getachew (2017) reported that the highest gross monetary value were in 50 % plant population density in common bean- rice inter crop. In line with research findings, Shaker and Nasrollahzadeh (2014) reported that greater gross income than monoculture in sorghum-mung bean intercrop.

6.5. Monitory advantage index (MAI)

The monetary advantage index (MAI) was calculated as described by Gosh (2004). MAI = value of combined intercrops × (LER−1) / LER. The higher the index value, the more profitable is the cropping system (Dhima K. *et al*. 2007). Positive MAI shows that intercropping is advantage (profitable) and a negative values of MAI indicates the disadvantage (economically unjustified) of the system. The analysis of variance in this finding shows that MAI was significantly affected by row arrangement, population density and their interaction (Appendix Table 3). The highest (16822 ETB ha^{-1}) MAI was when sorghum intercrop with mung bean in 1S:1M row arrangement and the lowest (3639 ETB ha^{-1}) was when sorghum intercrop with mung bean in 3S:1S row configuration (Table 11). A negative MAI indicates that inter cropping of sorghum with mung bean in that treatment was dis advantages and not ideal in the study area and the lowest as well as the negative value of MAI is because of the lowest in total LER. Willey (1979) confirmed that the treatments that have highest total LER will have the highest MAI and the lowest total LER have a negative MAI and this research findings is in line with Willey (1979). Similarly, Ashenafi (2016) also reported in maize- haricot bean inter crop, maximum MAI value were achieved in 1:1 maize- haricot bean inter crop.

Table 11: Main effect of sorghum mung bean intercrops on gross monetary value, total gross monetary value and monetary advantage index

RA	GMVS	GMSM	TGMV	MAI
1S:1M	55641^{b}	22609^{a}	78250^{a}	16822^{a}
2S:1M	60049^{a}	13982^{b}	74032^{b}	11847^{b}
3S:1M	56211^{a}	9924^{c}	66135c	3639^{c}
P(0.05)	*	**	**	**
PD				
50%	56148^{b}	13902^{c}	70050^{b}	7876^{c}
67%	61324^{a}	15600^{b}	76924^{a}	14841^{a}
100%	54429^{b}	17013^{a}	71443b	9591^{b}
P(0.05)	**	**	**	**
RA × PD	**	**	**	**
C.V (%)	5.97	7.09	4.89	30.27

*Where, RA, row arrangement, PD, population density, GMVS, gross monetary value of sorghum, GMVM, gross monetary value of mung bean, TGMV, total gross monetary value, MAI, monetary Advantage index, C.V, coefficient of variation, RA x PD, interaction of row arrangement with plant population densities, Ns, non-significance and ** significance at 1% level of probability.*

Similarly, Murad and Mohammad (2014) indicated maximum MAI value were obtained in planting of sunflower with mung bean in 1:1 planting pattern of sunflower with mung bean. The highest (14841 ETB ha^{-1}) MAI was obtained when sorghum intercrop with 67% plant population density of mung bean and the lowest (7678 ETB ha^{-1}) MAI was achieved when sorghum was inter crop with mung bean in 50% population of mung bean (Table 12). In contrasting with this research findings, Megersa *et al.* (2020) reported that maximum MAI were in 50% population density when of soybean in soybean-maize intercrop. In the interaction result listed in table 12, the value MAI was positive for all treatment combinations except in treatment in 3S:1M × 50%. In this research findings, the highest MAI (21493 ETB ha^{-1}) was obtained from 50%

population density of mung bean intercropped with 1S:1M row arrangement (Table 12). This indicated that, planting sorghum with mung bean in 1S:1M row arrangement combined with 50% plant population density of mung bean is more economically feasible in the test location.

The lowest (-6961 ETB ha^{-1}) MAI was obtained in 3S:1M sorghum mung bean row arrangement with 50% plant population density of mung bean and also a negative MAI was in sole sorghum and sole mung bean. In line with research findings, Yayeh *et al.* (2014) reported a low (negative) MAI in cereals (barley, wheat and finger millet) with lupine inert crop. In this research result, there was 24.87 monetary advantage over sole sorghum when sorghum was planted with 1S:1M row arrangement with 50% plant population density than planting sorghum alone.

Table 12: Interaction effect of sorghum mung bean inter crop on gross monetary value, total gross monetary value and monetary advantage index

Treatment combination	GMVS (ETB^{-1})	GMVM (ETB^{-1})	TGMV (ETB^{-1})	MAI (ETB^{-1})
1:1 × 50%	63429[a]	19880[b]	83309[a]	21493[a]
1:1 × 67%	57740[abc]	19760[b]	77500[ab]	15808[ab]
1:1 × 100%	45755[d]	28187[a]	73942[bc]	13165[bc]
2: 1 × 50%	56013[c]	15093[c]	71106[cd]	9097[cd]
2:1 × 67%	63648[a]	13800[cd]	77448[ab]	15176[bc]
2:1 × 100%	60487[abc]	13053[d]	73541[bc]	11268[bc]
3:1 × 50%	49003[d]	6733[f]	55737[e]	-6961[e]
3:1 × 67%	62584[ab]	13240[cd]	75824[bc]	13538[bc]
3:1 × 100%	57045[bc]	9800[e]	66845[cd]	4340[d]
P(0.05)	**	**	**	**
C.V (%)	5.97	7.09	4.89	30.27

*Where, GMVS, gross monetary value of sorghum, GMVM, gross monetary value of mung bean, TGMV, total gross monetary value, and MAI, monetary advantage index, Ns, non- significance and ** significance at 1% level of probability.*

3.7. Economic Analysis of the Component Crop (Partial budget analysis)

Partial budget analysis is mostly done to determine the profitability of treatments. It is usually done following the methodology prescribed by CIMMYT (1988). Cost benefit analysis was done to determine the relative economic returns on the applied treatments using the prevailing market prices of sorghum and mung bean. The yields of the experimental crops were adjusted by 10% downwards due to management level variability between a researcher and a farmer activity (CIMMYT, 1988). The price of sorghum and mung bean was obtained from local market via personal communication with sorghum and mung bean producers and retailers in Lalibela, North Wollo, which was the nearest market to the study area. Gross benefit was estimated as the product of the adjusted gain and straw yield of sorghum (kg ha^{-1}) and only the seed yield of mung bean (kg ha^{-1}) as the straw yield of mung bean is not commonly used by the farmers in the study area multiplying current by market price at harvest. A sale price for sorghum grain yield and mung bean seed yield were 21 Birr kg^{-1} and 48 Birr kg^{-1} respectively at the time of harvesting and the price of sorghum stalk were 110 per "shekme" after converting the biomass of the stalk to shekme.

Net benefit was calculated by subtracting the total cost of production from the gross benefit. The cost of production includes: current fertilizer cost; NPSB and Urea was 36.08 and 18.42 Birr kg^{-1} respectively, seed cost of sorghum and mung bean was 25 Birr kg^{-1} and 80 Birr kg^{-1}, respectively. Cost of labour in the area is 150 Birr day^{-1} and the cost of karate chemical for mung bean to manage of flea beetles insect at seedling level was ½ L ha^{-1} in 1800 Birr L^{-1} and its cost was doubling as it spray two times. Dominant treatments were analysed by arranging the treatments in terms of increasing variable costs. A treatment is dominant when it has a higher cost but a lower net benefit than any preceding treatment. Finally, marginal rate of returns were calculated (MRR), where the percentage change in net benefit over change in total variable cost in moving from a lower cost treatment to a higher one (Table 13). All the treatments were arranged from the highest to the lowest in terms of profitability. This was achieved by dividing the total variable cost by the net benefit multiplied by 100.

The partial budget analysis result of this research indicated, the highest net benefit (83646.51 ETB ha^{-1}) was in 1S:1M with 50% plant population density while the lowest net benefit (45773.46 ETB ha^{-1}) and (57038.4 ETB ha^{-1}) was obtained in sole mung bean and in 3S:1M × 50% plant density of mung bean, respectively. Only four of the treatments was none dominated and considered for the MRR analysis (Table 13). Acceptable MRR was obtained in 1S:1M × 50% plant population density, 3S:1M × 67% and 2S:1M × 67% row arrangement and plant population density of mung bean, respectively. In this experimental research result, there was 17.65% ETB ha^{-1} net benefit advantage over planting sorghum alone and 45.27% ETB ha^{-1} net benefit advantage as compering planting mung bean alone when planting (intercropping) sorghum in 1:1 row arrangement with 50% population density of mung bean.

8. Yield and economic advantage of sorghum-mung bean intercrop over planting alone

8.1. Yield advantage of sorghum-mung bean intercrop over planting alone

Willey, (1979) stats that inter crop is productive when the sum of the intercrop yield is greater than yield of the individuals (the sole cropped). In this experiment, the highest (12. 54%) and (63.64%) yield advantage were made over planting sole sorghum and mung bean in 1S:1M × 50% row arrangement and population density of sorghum mung bean intercrop (Table 14). Similarly, Ashenafi (2016) also reported that yield advantage of maize in intercrop of maize – haricot bean up to 20-48% over planting maize as sole. Erythrina *et al.* (2022) also reported that 44% yield advantage of rice were in intercropping of rice-maize and 63% advantage of maize over planting each alone and 54% yield advantage of soybean in rice- soybean inter crop. Also Tolera *et al.* (2005) report that 27% yield advantage of maize in maize climbing bean than sole maize and 403% yield advantage of climbing bean than planting climbing bean as a sole. Enatalem *et al*. (2022) also reported that 20.3% more productive (yield advantage) of maize than sole cropping system. Also Alemayehu *et al*. (2016) reported that 28% more yield advantage in maize common bean intercropping than solitary and 23% yield advantage in maize-narrow leaf lupine inter crop over sole maize.

8.2. Economic (net benefit) advantage of sorghum-mung bean intercrop

In this experimental research finding, maximum net benefit advantage (21.43%) over planting sorghum alone and maximum net benefit (45.27%) over planting mung bean alone was made 1S:1M × 50% row arrangement and plant population density of mung bean in sorghum mung bean inter crop (Table 15). Maximum net return were also reported in intercrop practices than sole sorghum (Erythrina *et al.,* 2022) and in line with this research finding, Zeru *et al.* (2019) also reported maximum net benefit with acceptable MRR were in 1:1 sorghum- cowpea row arrangement with in 50% (40 cm × 20cm) cow pea population density than sole sorghum and cow pea in sorghum- cow pea intercrop. Also Negasa *et al.* (2021) were reported maximum net benefit in maize soya bean intercrop than planting each alone and also in line with research result, Habtamu and Tadele (2021) confirms that, highest net income accrued from intercropping of sorghum-haricot bean

Table 13: Economic analysis of intercropped sorghum with mung bean

Treatment	TVC	ASrY	ASrSY	AMgY	SrGB	MgGB	TGB	NB	MRR (%)
SSr	5825.23	2725.05	5826.60	00	74705.79	000	74705.79	68880.56	
3:1 × 50%	7031.83	2100.17	4500.48	134.69	57604.96	6465.31	64070.27	57038.44	D
3:1 × 67%	7117.83	2682.21	5771.53	264.80	73640.93	12710.10	86351.24	79233.41	800
3:1 × 100%	7313.43	2444.79	5386.72	196.60	67500.68	9408.10	76908.77	69595.34	D
2:1 × 50%	7683.23	2400.58	6696.21	301.86	70500.78	14489.28	84990.06	77306.83	D
2:1 × 67%	7843.23	2727.84	6453.38	275.94	76644.71	13245.12	89889.83	82046.60	387
2:1 × 100%	8155.23	2592.13	5978.70	261.00	72370.75	12528.00	84898.75	76743.52	D
SMg	8608	00	00	1132.95	000	54381.46	54381.46	45773.46	D
1:1 × 50%	9119.63	2718.41	5531.58	397.60	73681.25	19084.90	92766.14	83646.51	125.3
1:1 × 67%	9407.63	2474.56	5576.05	395.20	68693.89	18969.55	87663.44	78255.81	D
1:1 × 100%	9965.23	1960.99	4962.72	563.73	56068.98	27059.18	83128.17	73162.94	D

Where TVC = total variable cost, ASrY = adjusted sorghum grain yield, ASrSY = adjusted sorghum straw yield, AMgY = Adjusted mung bean seed yield, SrGB = sorghum gross benefit, MgGB = mung bean gross benefit, TGB = total gross benefit, SSr= sorghum sole, SMg = sole mung bean, NB = net benefit and MRR (%) = Marginal rate of return in percent.

Table 14: Yield advantage of sorghum mung bean inert crop than planting each alone

Treatment Combination	Sorghum yield Kg ha^{-1}	Mung bean yield Kg ha^{-1}	Total yield Kg ha^{-1}	Yield advantage over sole	
				Sorghum (%)	Mung bean (%)
1:1 × 50%	3020.45	441.78	3462.23	12.54	63.64
1:1 X 67%	2749.51	439.11	3188.62	5.04	60.52
1:1 × 100%	2178.88	626.37	2805.25	-7.93	55.12
2:1 × 50%	2667.31	335.41	3002.72	-0.83	58.07
2:1 × 67%	3030.93	306.67	3337.6	9.28	62.28
2:1 × 100%	2880.41	290.07	3170.48	4.49	60.29
3:1 × 50%	2333.52	149.63	2483.15	-21.93	49.30
3:1 × 67%	2980.23	294.22	3274.45	7.53	61.55
3:1 × 100%	2716.43	217.78	2934.21	-3.19	57.09
Sole	3027.83	1258.83	—	—	--------

Where, row arrangement is sorghum- mung bean respectively.

than planting in separated especially in 1 Sorghum: 2 haricot bean sequence. Also In line with finding, Alemayehu *et al*. (2016) found that planting maize-common bean/maize/lupine intercrop increased net returns compared to planting each crop separately.

Table 15: Economic (net benefit) advantage of sorghum-mung bean intercrop than planting each alone

Treatment combination	Total NB (ETB^{-1})	NB % over sole sorghum	NB % over sole mung bean
1:1 x 50%	83646.51	21.437	45.277
1:1 x 67%	78255.81	13.610	41.507
1:1 x 100%	73162.94	6.217	37.436
2:1 x 50%	77306.83	12.233	40.789
2:1 x 67%	82046.6	19.114	44.210
2:1 x 100 %	76743.52	11.415	40.355
3:1 x 50%	57038.44	-17.192	19.749
3:1 x 67%	79233.41	15.030	42.229
3:1 x 100%	69595.34	1.037	34.229
sole sorghum	68880.56		
sole mung bean	45773.46		

Where, row arrangement is sorghum- mung bean respectively, NB, net benefit, ETB, Ethiopian birr.

CONCLUSION

The results of the experiment indicate that some of the phenological data of sorghum were not significantly influenced by neither the main effects, nor the interactions and cropping system. Both the main effect as well as interaction effect of row arrangement, plant population density of mung bean and cropping system had significantly influenced plant height, panicle length, above ground biomass, grain yield, and harvest index of sorghum. Maximum values of above ground biomass (7170.4 kg ha^{-1}) of sorghum was recorded when sorghum was planted with 2S:1M × 67% row arrangement and plant population of mung bean followed by (7140.23 kg ha^{-1}) in 1S:1M × 50% row arrangement and population of mung bean. Also the interaction effect of row arrangement and plant population density shows highly significant effect on grain yield of sorghum and the highest grain yield of sorghum (3030.93 kg ha^{-1}) was obtained in the interaction of 2S:1M row arrangement of sorghum mung bean with 67% of mung bean population density followed by 1S:1M × 50% (3020.45 kg ha^{-1}).

Mung bean grain yield, above ground biomass and harvest index was significantly affected ($p<0.01$) and ($p<0.05$) by the interaction of row arrangement and population density. The highest grain yield of mung bean (626.37 kg ha^{-1}) was obtained in the interaction of 1S:1M × 100% row arrangement and plant population density of mung bean while the lowest grain yield of mung bean (149.63 kg ha^{-1}) was in the interaction of 3S:1M × 50% row arrangement and plant population density of mung bean. The highest and the lowest harvest index of mung bean was achieved in 2S:1M × 50% and 3S:1M × 50% row arrangement and plant population density of mung bean.

System productivity in sorghum mung bean inter crop in the study area was assessed by using total land equivalent ratio, competitive ratio, area time equivalent ratio, gross monetary value, monetary advantage index and using acceptable level of marginal rate of return (MRR). In all combinations, the total value of land equivalent ratio was greater than unity except in 3S:1M × 50% and this indicates that in most of the treatment combination inter crop sorghum with mung bean was advantages and the highest total LER (1.35) was obtained in 1S:1M sorghum mung bean row arrangement with 50% plant population density of mung bean and the lowest total LER (0.89) was obtained in 3S:1M row arrangement with 50% plant population density of mung bean. The competitive ratio was higher than one in all treatments and the highest was on sorghum than mung bean and it indicates that sorghum was more competitive than mung bean.

Beside to total LER, the MAI was higher than one and positive in all treatment combinations except a negative MAI in 3S:1M row arrangement with 50% plant population density of mung bean. A negative MAI indicates that inter cropping of sorghum with mung bean in that treatment was dis advantages and negative value of MAI is because of the lowest in total LER. The highest value of MAI (21493 ETB ha^{-1}) was recorded in 1S:1M row arrangement with 50% population density of mung bean followed by 1S:1M with 67% (15808 ETB ha^{-1}) and the lowest MAI was in the combination of 3S:1M × 50% (-6961 ETB ha^{-1}). The highest net benefit (83309 ETB ha^{-1}) with an acceptable level of MRR (125.3) was obtained when mung bean was intercropped with in 1S:1M with 50% (40 cm X 20 cm inter and intra row spacing) of mung bean plant population density. Intercropping sorghum in a 1S:1M row arrangement within 50% population density of mung bean gives 12.54 and 63.65% kg ha^{-1} yield advantages and 21.43% and 45.27% ETB ha^{-1} net benefit advantages respectively than planting sorghum and mung bean alone and the outcome made it very evident that the additive intercropping combination of sorghum and mung bean had advantages over cultivating any of them in a stand alone in the study area.

According to the result of this study, intercropping of sorghum and mung bean in 1:1 row arrangement with 50% (125,000 ha^{-1} or 40 cm × 20 cm inter and intra row spacing of mung bean when intercropped with sorghum) mung bean plant population density give better yield and economic benefit. So, this treatment is recommended for farmers in the study area and other similar agro ecologies. However, the present study is conducted in specific area in one year and to give more reliable recommendation, the experiment need to be repeated across locations and years.

Accessibility of the data (Data Availability)

Data used to support the findings of this study are available from the first author upon request.

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APPENDIX

Appendix Table 1: Mean square value (ANOVA) of Aow Arrangement and population density of sorghum-Mung bean intercropping on sorghum growth, yield and yield related parameters

S.V	D.f	DsH	DsM	Ph	Pl	BM	TSW	GY	HI
REP	2	—	—	—	—	—	—	—	—
RA	2	12^{ns}	23.4^{ns}	46.6^{**}	24.6^{**}	3558609^{**}	11.8^{ns}	109791^{**}	86.5^{**}
PD	2	19^{ns}	2.1^{ns}	56^{**}	17.8^{**}	1146197^{**}	3.6^{ns}	433950^{**}	21.9^{ns}
RAX PD	4	$11.6^{n}s$	0.6^{ns}	374.2^{**}	21.7^{**}	1030701^{**}	2.4^{ns}	367976^{**}	39.2^{**}
Error	16	7.2083	7.8	5.198	1.0381	41374	3.7	16539	6.7
Total	26	—	—	—	—	—	—	—	—
C.V (%)		4.14	2.24	2.08	5.17	3.27	6.4	4.66	5.94

*Where s.v, source of variation, DsH, days to heading, DsM, days to maturity, ph, plant height, pl, panicle length, BM, above ground dry biomass, TSW, 1000 seed weight, GY, grain yield, HI, harvest index, C.V, coefficient of variation, ns, non-significance, * significance at 5 % probability level, ** significance at 1 % level of probability.*

Appendix Table 2: Mean square value (ANOVA) of row arrangement and population density of sorghum-mung bean inter crop on phenology, growth and seed yield and related traits mung bean

S.V	D.f	Dsf	DsM	PH	NPP	NSpP	TSW	BM	SY	HI
REP	2	—	—	—	—	—	—	—	—	—
RA	2	1^{ns}	1.1^{ns}	25.7^{ns}	8.2^{ns}	0.1^{ns}	53^{*}	2995103^{**}	186243^{**}	55.9^{**}
PD	2	4^{ns}	0.3^{ns}	7.27^{ns}	99^{ns}	0.6^{ns}	42^{**}	871660^{**}	11052^{**}	83.3^{**}
RA X PD	4	4^{ns}	1.3^{ns}	56.1^{*}	105^{**}	0.3^{ns}	128^{**}	472685^{**}	21341^{**}	80.7^{**}
Error	16	2.0	2.8	12.3	8.68	0.6	8.1	8555	351	7.9
Total	26	—	—	—	—	—	—	—	—	—
C.V (%)		2.5	1.2	6.7	9.8	6.8	5.09	6.3	5.38	12.02

Where S.V, source of variation, RA, row arrangement, PD, population density, ARXPD, interaction of row arrangement with population density, C.V, coefficient of variation, DsF, days to flowering, DsM, days to maturity, Ph, plant height, NPP, number of pod per plant, NSPP, number of seed per pod, HSW, 100 seed weight, BM, above ground dry biomass, SY, seed yield and HI, harvest index.

Appendix Table 3: Mean square value of some inter crop indexes in sorghum mung bean inter crop under different row arrangement and population density of mung

S.V	PLERS	PLERM	TLER	CRS	CRM	ATER	GMVS	GMVM	TGMV	MAI
Rep	—	—	—	—	—	—	—	—	—	—
RA	0.01231^{*}	0.11716^{**}	0.10618^{**}	0.3793^{**}	0.10414^{**}	0.02963^{**}	$5.173e+07^{*}$	$3.377e+06^{**}$	$3.404E+08^{**}$	$3.989 e+08^{**}$
PD	0.02881^{**}	0.00646^{**}	0.02963^{**}	0.088^{*}	0.24280^{**}	0.00425^{ns}	$1.159e+06^{**}$	$2.184e+06^{**}$	$1.188E+08^{**}$	$1.185 E+08^{**}$
RAX PD	0.03812^{**}	0.01291^{**}	0.03598^{**}	0.0778^{**}	0.04038^{**}	0.02406^{**}	$1.562^{**}e+08$	$4.158e+08^{**}$	$1.14E+08^{**}$	$1.403E+07^{**}$
Error	0.00284	0.00038	0.00318	0.00686	0.00477	0.00358	1.17E+06	1.07E+06	1.27E+07	1.24E+07
Total	—	—	—	—	—	—	—	—	—	—

*Where, RA, row arrangement, PD, population density, RAXPD, interaction of row arrangement with plant population density, PLERS, partial land equivalent ratio of sorghum, PLERM, partial land equivalent ratio of mung bean, TLER, total land equivalent ratio, CRS, competitive ratio of sorghum, CRM, competitive ratio of mung bean, ATER, area time equivalent ratio of the system, * significance at 0.05 probability level and ** significance at 0.01 probability level. GMVS, gross monetary value of sorghum, GMVM, gross monetary value of mung bean, TGMV, total gross monetary value, and MAI, monetary advantage index*