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Original Paper

Optimization of Seed Proportions of Mung Bean (*Vigna Radiata L.*) and Planting Patterns for Sorghum (*Sorghum Bicolor L.*) -Mung Bean Intercropping in Lasta District, North Wollo Zone, Ethiopia

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Abstract*— Planting patterns and seed ratio of the added crops determine the success or failure of intercropping. In the Lasta district, intercropping sorghum and mung bean is a common practice. However, there is a dearth of research on the optimal proportions of mung bean seeds added and the proper planting patterns for sorghum-mung bean intercropping. Therefore, this experiment was conducted in 2022 at Lasta district, North Wollo Zone, to determine the optimal mung bean seed proportion, to identify the best sorghum-mung bean planting pattern and their combinations. Three seed proportions of mung bean (100%, 67% and 50%) with three sorghum-mung bean planting patterns (1S:1M, 2S:1M, and 3S:1M) including sole sorghum and mung bean as a control with three replication were tested using RCBD factorial arrangement. Data such as days to heading and maturity, panicle length, plant height, biomass grain yield for main crop and days to 50% flowering, 90% physiological maturity, pods per plant, branches per plant, seeds per pod, biomass and seed yield were collected and analysis using SAS software. The analysis of variance indicated that most of the study traits were significantly affected by the treatments. The highest grain yield of sorghum (3030.93 kg ha-1 and 3020.43kg ha-1) was obtained within 2S:1M x 67% and 1S:1M x 50% of planting pattern and seed proportion of mung bean, respectively. Intercropping sorghum in a 1:1 planting pattern within 50% seed proportion of mung bean gives 12.54 and 63.65% yield advantages over planting sorghum and mung bean alone respectively. Therefore, adding the 50% (125,000 plants ha-1) mung bean seed proportion with a 1S:1M planting pattern is recommended for intercropping in the target area, based on its better compatibility, and yield productivity. This practice will optimize land use, improve yields, ensure nutritional balance and food security, enhance soil fertility, mitigate climate change, and contribute to more sustainable farming in the district compared to the separate planting.

Keywords*— *Agronomic traits, planting patterns, Seed proportions, Yield

I. INTRODUCTION

Sorghum (Sorghum bicolor L.) is a component of the genus Sorghum, which is characterized by its ability to grow in several environments [6]. The cultivation of sorghum is primarily focused on the production of its grain and stalks, which are utilized as food, fodder, and building materials in underdeveloped regions [26]. In contrast, mung beans (Mungo bean, Phaseolus vulgaris L.) are cultivated worldwide in tropical and subtropical climates [14]. This plant is grown primarily for its edible seeds, which are rich in protein, and for its fresh sprouts. Mung beans are also used in stews, bread, and biscuits [26].The cultivation of mung beans has been shown to enhance soil fertility, reduce growth cycles, and minimize water requirements [26]. Furthermore, intercropping and the exchange of crops for cash or commodities is the basic beneficial of mung bean crop [2].

Intercropping is defined as the process of cultivating two or more distinct crop species or varieties in a concurrent manner in various row configurations and with different seed proportions on the same plot of land [12 and 29]. The establishment of sustainable food production systems necessitates the intercropping of grains and legumes, particularly in scenarios where farmers utilize minimal to no fertilizer and the soil contains negligible levels of organic matter [3]. This practice is more productive than monoculture in several ways, including the utilization of resources more efficiently, including water, nutrients, and solar energy [13]. The outcomes of intercropping systems include increased crop yield, more effective use of resources, and increased revenue [17and 18] for ecological sustainability and intensification reduced input costs (lower expenses associated with fertilizer and pesticide utilization), enhanced yield stability, and a reduction in the risk of crop failures due to diversity [3 and 16].

The practice of intercropping cereals and legumes plays a pivotal role in subsistence farming, both in developed nations and in the production of food crops in developing countries, particularly in regions with limited irrigation resources [28]. The practice of cereal-legume intercropping has been shown to aid in the control of weeds, enhance quality, extend availability, and conserve fodder [24]. A variety of factors have been identified as influential in the performance and effectiveness of intercropping systems. These factors include the proportion of seeds utilized as intercrops and the configuration of planting patterns, the selection of crops and cultivars, the amount sown, agronomic management (including water, available nutrients, and their application, as well as plant population densities), and the ability of crops to optimize resource use. The selection of appropriate crop combinations is paramount in cereal-legume intercrop systems, given the influence of population density and spatial configuration on system performance (Yang et al., 2022).

In the semi-arid region of the Lasta district, which is situated within the North Wollo zone, sorghum and mung beans represent two of the crops cultivated. The predominant cropping practice in this area is continuous sorghum mono-cropping, which involves the cultivation of the same crop over extended periods without the implementation of intercropping or crop rotation. This practice has led to a persistent decline in soil fertility, resulting in a gradual decrease in productivity over time. The incorporation of legumes, such as mung bean, common bean, cowpea, and others, into the cropping system has been identified as a potential strategy to enhance soil fertility and mitigate climate change. Legumes serve to fix atmospheric nitrogen (N) and reduce the availability of rare soil nutrients, thereby increasing output with minimal input and ensuring nutritional balance and food security. However, the combination of mono-cropping practices with inadequate agronomic techniques has resulted in suboptimal sorghum yields and declining soil fertility in the area. The research hypothesis posits that the utilization of diverse seed proportions of mung bean and the implementation of sorghum-mung bean intercropping have a substantial influence on the yields of the constituent crops. The study is designed to test this hypothesis through field experiments involving various treatment combinations of mung bean seed proportions and sorghum-mung bean intercropping patterns. The study's outcomes could include the identification of the optimal proportions of mung bean seeds and the planting pattern of sorghum-mung bean intercropping that can give the highest yield. Furthermore, the study could give valuable insights into the potential benefits of intercropping as a sustainable farming practice that can improve yields and crop diversity and reducing the need for chemical fertilizers and pesticides used.

The findings of this study have the potential to inform farmers and policymakers in semi-arid areas of Lasta district, North Wollo zone, and beyond on best practices for intercropping mung bean and sorghum. The Sekota Dry Land Agricultural Research Center has recommended Rassa (N-26), a mung bean variety, and Melkam, a sorghum variety, for the study area. However, there is lack of information regarding the seed proportions of mung bean when intercropped with sorghum, as well as the sorghum-mung bean intercrop row configuration (planting pattern) in the semi-arid area of Lasta district, North Wollo Zone. Consequently, the exploration of appropriate seed proportions of mung bean and row configurations for intercropping sorghum and mung bean in the study area emerges as a promising research avenue. To date, there has been a paucity of research in this area, particularly concerning the effects of varying seed proportions of mung bean and the planting pattern of mung bean in conjunction with sorghum on the yield and related parameters of the component crops. Consequently, it is challenging to recommend optimal seed proportions of mung bean and intercropping pattern for this study area. Consequently, the development of optimal agronomic practices (ideal seed proportions and planting patterns during intercropping) is imperative to enhance production and productivity per unit area. To this end, the present study was conducted to determine the optimal mung bean seed proportion for intercropping with sorghum, to identify the best sorghum-mung bean planting pattern, and to identify the most suitable combination for the Lasta district for sustainable crop production.

II. Materials And Methods

A. Description of the Study Area

The experiment was conducted in the north Wollo Zone of the Amhara Region, specifically in the Shemseha area of Lalibella town (the nearest to Lalibella airport) in the Lasta District, during the 2022 cropping season (Figure 1). The area is characterized by a unimodal rainfall pattern that extends from June to late August or early September. The area is situated in the easternmost part of Ethiopia, at a considerable distance from both Addis Ababa (the capital of Ethiopia) and Bahir Dar (the capital of the Amhara Region). It is located within the easternmost region of the Amhara Region, specifically within the North Wollo Zone. The region is distinguished by a unimodal rainfall pattern, which typically extends from June to late August or early September. The agro-ecological characteristics of the district exhibit variability, ranging from the Woyna Dega Midlands to the Kola Lowlands, with the presence of sandy loam soil. The geographical coordinates of the research site are specified as 110°58'18" North latitude, 38°58'54" East longitude, with an altitude of 1,963 meters above sea level (m.a.s.l.).

The mean annual minimum and maximum rainfall are 569 millimeters and 760 millimeters, respectively. The site has a mean maximum temperature of 24.70 degrees Celsius and a mean minimum temperature of 13.60 degrees Celsius. The predominant agricultural practices in the area encompass sole cropping, mixed cropping without specific row arrangement and appropriate plant population density, and crop rotation without maintaining legume cereal principle. The major crops cultivated in the area surrounding Lalibela include 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.), and haricot bean (Phaseolus vulgaris L.). The most common cropping systems observed in the study area include intercropping of sorghum with mung bean, sorghum with haricot bean, tef with safflower, sorghum with faba bean, sorghum with tef, and wheat with sunflower (Mekonene and Daniel, May 20, 2021, and personal observation).

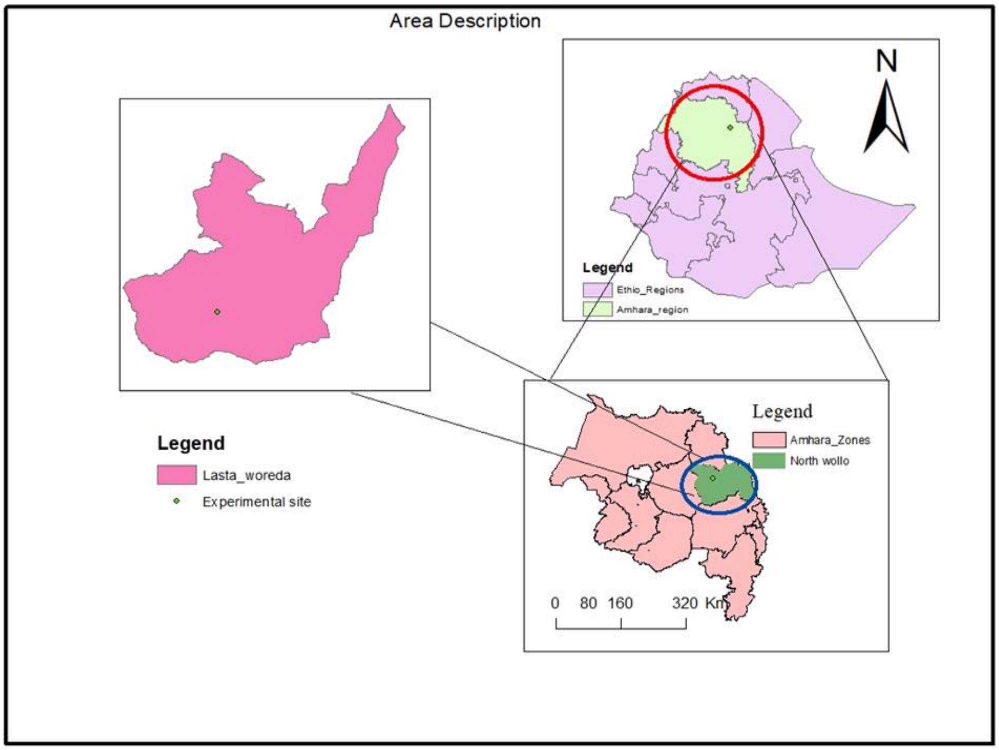

Fig. 1. Location of the study area at Lasta District during 2022 cropping season

B. Experimental Materials

1) Plant Materials used for the experiment

The early-maturing sorghum variety Melkam was utilized as the primary crop in the study, and it has been identified as a high-yielding and early-maturing crop variety within the study area. The mung bean varieties Rasa (N-26), which was released by MARC in 2011, was employed as the companion crop in the additive series. The selection of these two crop species for intercropping was based on their adaptability in the area, differences in their morphological characteristics, and yield potential. (Table 1).

TABLE I. DESCRIPTION OF EXPERIMENTAL MATERIAL (VARIETIES) 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}

Source: (MOARD, 2009; MOA, 2011

2) Fertilizer Material and Application

A uniform recommendation of 100 kg NPSB (18.9, 37.7, 6.9, and 0.1%) ha^{-1} and 50 kg urea (46% N) ha^{-1} was implemented for all sole and intercropped sorghum plots. The nitrogen was applied in two installments: half during planting, and the remaining half at the knee-height stage of sorghum development, which corresponds to the sorghum plant producing six to eight leaves. For the sole treatment of mung bean, 100 kg NPSB ha^{-1} were utilized and fully applied at the time of planting. No nitrogen fertilizer was applied for the sole treatment of mung bean.

3) Experimental Design, Treatments and filed Procedures

The experiment was meticulously designed using a randomized complete block design under factorial arrangement, with each the treatment replicated thrice to ensure statistical robustness. The treatment comprised a total of 11 distinct treatments. The three inter-cropping patterns 1 sorghum: 1 mung bean, 2 sorghum:1 mung bean, and 3 sorghum:1 mung bean, (1S:1M, 2S:1M, and 3S:1M in additive series) were utilized, with three mung bean planting densities: The experiment was conducted in three distinct planting densities, designated as D1 (50%), D2 (67%), and D3 (100%), in conjunction with sole crops of sorghum and mung bean as a control. Each plot measured 5 meters in length by 3.75 meters in width (18.75 square meters) within a net plot size of 11.25 square meters, with pathways between plots and blocks measuring 0.5 meters and 1 meter, respectively. The experimental design incorporated five rows, with approximately 33 plants maintained per row in a plot for the primary crop. The spacing configuration was 0.75 meters between rows and 0.15 meters between plants, resulting in a total utilization of 88,889 and 166.65 plants per hectare and per plot, respectively. For the sole treatment of mung bean, a 40-centimeter space was utilized between rows, while the intra-row spacing was adjusted based on the specific treatment. The population of sorghum plants in both sole cropping and intercropping treatments was equivalent, with a total of 88,889 plants. This consistency is attributed to the additive series principles underlying the design, which maintains the sorghum plant population at 100% for both intercropping and sole cropping treatments. The sole mung bean crop was arranged in nine rows, with 50 plants per row in each plot. The spacing between plants within a row was strategically modified to achieve the desired plant density (i.e., 10, 15, and 20 cm).The experimental land (plot) was meticulously prepared and uniformly labeled in May and planted in late June 2022. The seeds were sown per row in July using the recommended seed rate of 15 kilograms per hectare, followed by thinning at a spacing of 0.15 meters between plants after two weeks of emergence for sorghum. Two seeds per pit of mung bean were sown in July and two weeks later, thinning to one plant per hole was done for mung bean intercropped and sole plot, following farmers' practices in the district. A chemical, Karate (0.4 L of the compound dissolved in 200 L of water per hectare) was applied via spray immediately following the emergence of mung bean plants, coinciding with the observation of foliage beetles on the leaves of the mung bean plants. This initial spray was intended to control flea beetles (Trirhabda flavolimbata). A subsequent spray was administered seven days after the initial spray, adjacent to the first spray. It is noteworthy that all agronomical practices were applied uniformly across each experimental plot, including a uniform, two-time hand weeding procedure executed concurrently for all experimental plots.

C. Data Collection and Measurements

1) Phenological and growth parameters of sorghum

Days to heading: this variable was calculated as the number of days required for 50% of sorghum plants in the plots to reach heading production. Days to physiological maturity (DPM) was recorded as the number of days required from planting to maturing by 90% of the sorghum plants in the plots. The DPM stage is characterized by yellowing of the leaves and hardening of the seeds of the sorghum plants in the plots. Plant height (cm) was measured as the distance from the soil surface to the base of the heading of ten plants selected at random from the net plot area. The measurements were taken at physiological maturities, and the mean was calculated for analysis. Panicle length (cm): panicle length from the ten sampled plants from the central rows of each plot was measured in centimeters and averaged to represent the panicle length.

2) Yield Components and Yield of Sorghum

The Thousand Kernels Weight (g) was determined by meticulously placing 1,000 kernels into three replicates, subsequently weighing them individually using a sensitive balance, and finally calculating their mean weight. Grain Yield (kg ha^{-1}): After harvesting, the seeds were manually threshed, cleaned, and dried. The yield was measured using an electronic balance per net plot base. It was then adjusted to 14% seed moisture content using a digital moisture tester. The yield was converted to hectare basis. The adjusted yield was calculated using the formula developed by Hellevang (1995). Adjusted grain yield is calculated as follows: 100-grain moisture content /100-standard grain moisture content X obtained yield per plot. Above-ground biomass (tonnes per hectare) was measured from the net plot area in two stages. In the initial stage, only the heads of sorghum were utilized. Following a two-week period, the leaves and stems were harvested. The summation of the head and other components of each plot were weighed after a three-day period of sun-drying. The Harvest Index (HI) was determined as the ratio of grain yield to above-ground biomass, multiplied by 100, and expressed as a percentage (Donald, 1962). This index was then converted into an economic yield by dividing it by the biological yield and multiplying the result by 100, thereby yielding a percentage value.

3) Phenological and growth Parameters of Mung Bean

Days to Flowering: This variable was determined as the number of days from planting to the period when 50% of the plants in each plot produce their first flower. The days to physiological maturity were defined as the number of days from planting to the point at which 90% of the plants in a given plot exhibited a change in foliage, characterized by the transition to yellow, and demonstrated seed hardening within the pods. The senescence of the leaves and the frees threshing of the seeds from the pods when pressed between the forefinger and thumb were used to indicate physiological maturity. Plant height (cm) was measured as the distance from the soil surface to the uppermost point of ten randomly selected plants from the net plot area at physiological maturity. The mean value was calculated for analysis**.**

4) Yield Components and Yield of mung Bean

The number of pods per plant was determined by meticulously enumerating ten haricot bean plants of uniform maturity, selected at random, and calculating the mean value for each experimental unit. The number of seeds per pod was recorded from ten randomly selected pods, and the mean was calculated. The thousand seed weight (kg) was determined by taking 1,000 seeds from each plot at random, weighing them using a sensitive balance, and adjusting the weight to 10% of the seed moisture content. The seed yield (kg ha-1) was measured using an electronic balance (steelyard) and subsequently adjusted to 10% seed moisture content using a digital moisture tester. The yield was then converted to the hectare basis. The aboveground biomass (ton per hectare) was determined after sun-drying the net plot area for 72 hours. The weight of this area was measured after one-day intervals, and the process was continued until the dry weight remained constant. The harvest index (HI) was calculated as the ratio of grain yield to aboveground biomass. This index was subsequently multiplied by 100 to obtain a percentage value. HI= grain yield or economic yield / biological yield (aboveground biomass).

III. Results And Discussions

A. Phenology and Growth Response of Sorghum

1) 50% Heading and 90% Maturity

The analysis of variance demonstrated that the days to heading and maturity of sorghum were not significantly influenced ($P > 0.05$) by the main effect and interaction effects of planting pattern and seed proportions of mung bean (Appendix Table 1). In a similar vein, [4, 5, 7, 11, and 30] reported that the days to maize maturity from maize-common bean intercropping were not affected by component planting densities. The analysis of variance (ANOVA) demonstrated that both the main effects and the interaction effects of planting pattern and seed proportions were significantly ($p < 0.05$) associated with the plant height of sorghum (Appendix Table 1). The sorghum plants exhibited the greatest plant height (119.4 cm) when mung bean was intercropped with sorghum in a 2S:1M planting pattern within 100% seed proportion of mung bean whole. Conversely, the sorghum plants demonstrated the shortest plant height (97.76 cm) in the 1S:1M planting pattern within 100% seed proportion of mung bean (Table 2). The analysis of variance demonstrated that both the main effects and the interaction effects of planting pattern and plant seed proportion significantly ($p < 0.05$) affected the panicle length of sorghum (Appendix Table 1). Furthermore, the analysis of variance revealed that the interaction effect of planting pattern and sorghum mung-bean seed proportion significantly ($p < 0.05$) affected the panicle length of sorghum (Appendix Table 1). The highest panicle length of sorghum (25.15 cm) was observed when mung bean was intercropped with sorghum at a 1S:1M ratio within 67% of the mung bean seed proportion, while the lowest (16.23 cm) was recorded with the 2S:1M planting pattern within 100% of the mung bean seed proportion (Table 2).

TABLE II. INTERACTION EFFECT OF SEED PROPORTION OF MUNG BEAN AND PLANTING PATTERN OF SORGHUM MUNG BEAN INTERCROP ON GROWTH AND PHENOLOGY OF SORGHUM

Treatment Combination	DsH (no)	DsM (no)	Ph (cm)	Pl (cm)
1:1 x 50%	62.33	124.33	116.88^{abc}	19.23^{cd}
1:1 x 67%	63.63	123.66	115.36^{b}	25.15^{a}
1:1 x 100%	66.66	124.33	97.76^{e}	20.3^{bc}
2:1 x 50%	64	122.33	118.09^{ab}	19.3^{cd}
2:1 x 67%	68	124.66	98.17^{e}	21.76^{b}
2:1 x 100%	65	123.33	119.4^{a}	16.23^{e}
3:1 x 50%	63	126	103.16^{d}	17.93^{de}
3:1 x 67%	64.12	127	113.05	17.12^{e}
3:1 x 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 1% level of probability

2) Yield Components and Yield of Sorghum

The analysis of variance on 1,000 kernel weights indicates that the main and interaction effects of row arrangement and plant population density are not statistically significant ($p > 0.05$) (Appendix Table 1). This finding aligns with those of several scholars, including [7, 8, 22 and 32, and 33]. These scholars reported that thousand kernel weight was not influenced by intercropping different cereal-pules or cereals-oil intercrop. However, [34] reported that 1000 kernels of sorghum were significantly affected by row arrangement and plant population of the component crop. The analysis of variance indicates that the above-ground dry biomass of sorghum was significantly influenced ($P < 0.05$) by planting pattern, seed proportion, and their interaction (Appendix Table 1). The interaction between planting pattern and seed proportion exhibited a significant effect on sorghum above ground dry biomass ($P < 0.05$) (Appendix Table 1). The maximum and minimum values recorded were 71.704 t ha-1 and 59.852 t ha-1, respectively, for the 2S:1M X 67% and 3S:1M X 50% planting patterns (Table 3).

The interaction effect of planting pattern, sorghum-mung bean intercrop, and mung bean seed proportion on grain yield of sorghum was found to be highly significant ($P < 0.01$) (Appendix Table 1). The interaction of the 2S:1M planting pattern of sorghum-mung bean intercrop at 67% seed proportion of mung bean and the 1S:1M planting pattern with 50% seed proportion of mung bean resulted in the highest sorghum grain yield (3030.93 kg ha-1). Conversely, the lowest sorghum grain yield (2178.88 kg ha-1) was observed in the 1S:1M planting pattern of sorghum-mung bean intercrop at 100% seed proportion of mung bean (Table 3). This phenomenon may be attributed to the exchange of nutrients during the pivotal phase of the cultivation of both crops. In accordance with the findings of [34] the interaction between row arrangement and population density of cowpea has been demonstrated to exert a substantial influence on the grain yield of sorghum. The yield of sorghum was found to be reduced when sorghum was intercropped with mung bean in different planting patterns.

APPENDIX TABLE 1. MEAN SQUARE VALUE (ANOVA) OF PLANTING PATTERN AND SEED PROPORTION OF MUNG BEAN IN SORGHUM-MUNG BEAN INTERCROPPING ON SORGHUM PEHNOLOGY, GROWTH, YIELD AND YIELD RELATED TRAITS

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

The harvest index, defined as the ratio of grain yield to dry biomass yield, exhibited a statistically significant ($P < 0.05$) variation due to row arrangement and the interaction between row arrangement and plant population density (Appendix Table 1). However, plant population density did not influence the harvest index of sorghum. The 3S:1M row arrangement of mung bean exhibited a higher harvest index (46.23%), while the 2S:1M row arrangement of mung bean resulted in a lower sorghum harvest index (40.06%). The observed variation in harvest index can be attributed to inter-specific competition for growth resources, such as moisture, nutrients, and light. Additionally, the increase in rows per hectare can potentially lead to an increase in plant population, which might also contribute to the observed variations in harvest index. In contrast to these findings, [8, 10, 22, and 33] reported that the harvest index is not significantly affected by row arrangement in maize-mung bean, sunflower-mung bean, and cluster bean-sesame intercrops.

This outcome is at odds with the findings reported by [19] who noted that the harvest index exhibited a statistically significant variation due to planting density. Specifically, they observed that the highest harvest index of 41.35% was attained at a soybean planting density of 25%, while the lowest harvest index of 35.8% occurred at a soybean planting density of 75%. A high harvest index is indicative of effective partitioning of dry matter to grain yield. However, the study's findings did not demonstrate a statistically significant impact of cropping system on harvest index. The analysis of variance also demonstrates a significant effect ($p < 0.05$) on the harvest index of sorghum in the interaction of row arrangement and plant population density of mung bean (Appendix Table 1). The interaction of 1S:1M x 50% and 2S:1M x 50% exhibited the highest harvest index (49.15%) and the lowest sorghum index (37.32%) (Table 3).

TABLE III. INTERACTION EFFECT OF SORGHUM-MUNG BEAN INTERCROPPING AND THE PROPORTION OF MUNG BEAN SEEDS ON THE YIELD AND RELATED PARAMETERS OF SORGHUM

Treatment Combination	DsH (no)	DsM (no)	Ph (cm)	Pl (cm)
1:1 x 50%	62.33	124.33	116.88^{abc}	19.23^{cd}
1:1 x 67%	63.63	123.66	115.36^{b}	25.15^{a}
1:1 x 100%	66.66	124.33	97.76^{e}	20.3^{bc}
2:1 x 50%	64	122.33	118.09^{ab}	19.3^{cd}
2:1 x 67%	68	124.66	98.17^{e}	21.76^{b}
2:1 x 100%	65	123.33	119.4^{a}	16.23^{e}
3:1 x 50%	63	126	103.16^{d}	17.93^{de}
3:1 x 67%	64.12	127	113.05	17.12^{e}
3:1 x 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, 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

B. *Phenology and growth parameters of mung bean*

1) *Days to 50% Flowering and 90% physiological Maturity*

The analysis of variance revealed that the proportion of seeds, the planting pattern of sorghum and mung bean, and the interaction did not have a significant impact ($P > 0.05$) on the days to 50% flowering and days to 90% maturity of mung bean (Appendix Table 2). Concurrently, [21] in sunflower/mung bean intercrop; [19] in maize-soybean intercrop; [23], [34] in sorghum-cowpea and [7] in sorghum-mung bean intercrop, reported that days to 50% flowering and 90% maturity were not significantly affected by the different planting pattern and seed proportion. The absence of a significant difference in the growth and phenological parameters of mung bean under the sorghum-mung bean intercrop may be attributed to the differential utilization of resources between the intercrop species and the possibility that the two crops do not share nutrients such as light, soil, and water during the flowering and maturity periods of the two crops.

With regard to the subject of plant height, the results of the analysis of variance demonstrated that planting pattern and the seed proportion of mung bean did not exert a significant influence on mung bean plant height (> 0.05) (Appendix, Table 2). Consistent with the findings reported by [20] and [19] found that plant height was not influenced by variations in planting pattern and seed proportion of mung bean. However, this finding is not in alignment with the results reported by [8] and [7]. These studies indicated that the arrangement of sorghum and mung bean intercrops significantly influenced plant height. The analysis of variance regarding the interaction of planting pattern and seed proportion reveals a significant effect on mung bean plant height in the mung bean sorghum intercrop (Appendix Table 2). The maximum (59.26 cm) and minimum (47.43 cm) plant heights of mung beans were observed when mung beans were intercropped with sorghum at a 2S:1M x50% and 3S:1M x50% ratio.

2) *Yield Components and Grain Yield of mung bean*

An analysis of variance was conducted to assess the impact of planting pattern and seed proportion on the number of pods per plant. The results indicated that these factors exhibited a non-significant effect ($P > 0.05$) on the number of pods per plant, as shown in Appendix Table 2. Furthermore, the interaction effect of these two factors was found to have a significant influence on the pod number per plant. This finding is consistent with the observations reported by [7, 20, and 22] who also noted that planting patterns significantly influenced the number of pods per plant. The analysis of variance revealed a significant interaction effect between planting pattern and seed proportion on the number of pods per plant (Appendix Table 2). The maximum and minimum number of pods per plant were observed in the 1S:1M x 100% and 1S:1M x 50% row arrangement, respectively, and these results are presented in Table 8. The number of seeds per pod was not significantly ($P > 0.05$) affected by the main and interaction effect of seed proportion and planting pattern (Appendix Table 2). This outcome may be attributed to the absence of nutrient computation during the critical period of the two intercrop species, attributable to the dissimilar nature of the two crops. This finding aligns with the conclusions drawn by [7, 22, and 23] reported that the number of seeds per pod did not exhibit a significant response to planting patterns and seed proportion of mung bean in sorghum-mung bean and in maize common bean intercrops. Additionally, [19] reported that the number of seeds per pod was not significantly influenced by plant population density and variety in maize-soybean intercrops. 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 (61gr) and the lowest (47.7 gr) 1000 seed of mung bean was when mung bean inter crop with sorghum in 2S;1m x 50 % and 3S:1M x 50 % .

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 t ha-1) above ground biomass of mung bean was in 1S:1M x 100% planting pattern and seed proportion (Table 4). Similarly, [30] reported that above ground biomass were significantly affected by both the interaction of row arrangement and plant population density. In this research findings, the highest above ground biomass (30.2 t ha-1) was recorded in the interaction of 1S:1M row arrangement with 100% seed proportion whereas the lowest above ground biomass of mung bean (10.67 t ha-1) was obtained in 3S:1M row arrangement with 50% seed proportion of mung bean (Table 4). 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.

APPENDIX TABLE 2. MEAN SQUARE VALUE (ANOVA) OF PLANTING PATTERN AND SEED PROPORTION OF MUNG BEAN PHENOLOGY, GROWTH, YIELD AND YIELD COMPONENTS ON 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	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

A statistical analysis of variance in sorghum mung bean intercrop revealed that the yield of mung bean grain exhibited a highly significant ($P < 0.01$) variation in relation to planting pattern, a significantly different ($P < 0.05$) variation in relation to seed proportion, and a highly significant ($P < 0.01$) variation in relation to their interaction (Appendix Table 2). Furthermore, mung bean seed yield demonstrated a highly significant ($P < 0.01$) interaction effect influenced by row arrangements and population density (Appendix Table 2). The maximum seed yield of mung bean (626.37 kg ha-1) was observed in the interaction of 1S:1M planting pattern (row arrangement) with 100% plant population density of mung bean (see Table 4). In contrast, the lowest seed yield of mung bean (149.63 kg ha-1) was observed in the interaction of 3:1 sorghum-mung bean planting pattern with 50% plant population density of mung bean (Table 4). The low seed yield of mung bean in this experiment is potentially attributable to the plant densities and lower row number compared to other treatments. This outcome aligns with the findings reported by [34] who observed that the maximum seed yield of cowpea was attained under the interaction of 1:1 sorghum-cowpea row configuration and 100% (10 cm) intra-row spacing of cowpea. The findings of [34] also demonstrated that the grain yield of mung bean increased with an increase in plant population. This phenomenon could be attributed to either a greater number of plants being established under the intercropping system or to a higher number of plants per unit area. A 72.81% yield reduction of mung bean was observed in intercropping systems with sorghum. The factors contributing to this decline in seed yield of mung bean may be ascribed to adverse shading effects on sorghum plants, which depressed growth and yield attributes of mung bean. Alternatively, the reduction in yield may be due to the sharing of growth resources during the growth periods of the two crop species, particularly during critical growth stages, or due to a lower mung bean plant population density in intercropping compared to sole cropping. Concurrently, [8] documented that the seed yield of mung bean in maize-mung bean intercropping exhibited a 60% reduction. This finding was further substantiated by [25] who reported that intercropping in maize-mung bean intercropping diminished the mung bean yield by 28% in comparison to mung bean monoculture.

A statistical analysis of variance in the sorghum-mung bean intercrop revealed that the yield of mung bean grain exhibited a highly significant variation ($P < 0.01$) concerning planting pattern, a significant variation ($P < 0.05$) regarding seed proportion, and a highly significant variation ($P < 0.01$) concerning their interaction (Appendix Table 2). Furthermore, mung bean seed yield demonstrated a highly significant interaction effect influenced by row arrangements and population density ($P < 0.01$) (Appendix Table 2). The maximum seed yield of mung bean (626.37 kg ha-1) was observed with the interaction of a 1S:1M planting pattern (row arrangement) and 100% plant population density of mung bean (Table 4). In contrast, the lowest seed yield of mung bean (149.63 kg ha-1) was noted with the interaction of a 3:1 sorghum-mung bean planting pattern and 50% plant population density of mung bean (Table 8). The low seed yield of mung bean in this experiment may be attributable to the plant densities and fewer rows compared to other treatments. This outcome aligns with the findings reported by [34] who observed that the maximum seed yield of cowpea was attained under the interaction of a 1:1 sorghum-cowpea row configuration and 100% (10 cm) intra-row spacing of cowpea. The findings of [34] also demonstrated that the grain yield of mung bean increased with higher plant population. This phenomenon could be attributed to either a greater number of plants established under the intercropping system or a higher density of plants per unit area.

TABLE IV. INTERACTION EFFECT OF SEED PROPORTION AND PLANTING PATTERN OF SORGHUM-MUNG BEAN INTERCROPS ON MUNG SEED YIELD AND RELATED YIELD COMPONENTS

Treatment combination	NPP (no)	SPP (no)	BM (t ha^{-1})	TSW (gr)	SY (kg ha^{-1})	HI (%)
1:1 x 50%	24.7^{d}	11.7	1955.6^{b}	58.9^{ab}	441.78^{b}	22.68^{cb}
1:1 x 67%	27^{d}	11.26	1540.7^{cb}	56.8^{ab}	439.11^{b}	28.58^{ab}
1:1 x 100%	40.3^{a}	11.36	3016.3^{a}	46.6^{c}	626.37^{a}	20.79^{cd}
2:1 x 50%	28^{cd}	11.4	1125.9^{cd}	61.5^{a}	335.41^{c}	29.87^{a}
2:1 x 67%	26.2^{d}	11	1303.7^{cd}	59.9^{a}	306.67^{cd}	23.77^{abc}
2:1 x 100%	32^{bc}	12	1481.5^{cd}	54.7^{b}	290.07^{d}	20.13^{cd}
3:1 x 50%	28^{cd}	11.3	1066.7^{d}	47.7^{c}	149.63^{f}	14.02^{d}
3:1 x 67%	35.8^{ab}	11.13	1422.2^{cd}	57.8^{ab}	294.22^{d}	23.13^{abc}
3:1 x 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*

3) Yield advantage of sorghum-mung bean intercrop than individual planting

According to [29] intercropping is regarded as productive when the aggregate yield of the intercrops surpasses that of the individual crops cultivated separately. In the present study, the sorghum-mung bean intercropping system, employing a 1S:1M x 50% planting pattern and mung bean seed proportion, yield advantage from 4.49 to 12.54% more than sole sorghum and 49.3 % up to 63.64% more than sole mung bean (Table 5). A similar outcome was reported by [2] who found that maize intercropping with haricot beans yielded 20–48% more than monoculture maize. Also [9] observed a 44% yield advantage for rice in rice-maize intercropping and a 63% advantage for maize, in addition to a 54% yield advantage for soybean in rice-soybean intercropping. Furthermore, [27] found a 27% yield advantage for maize in maize-climbing bean intercropping compared to sole maize, as well as a 403% yield advantage for climbing bean compared to planting it as a sole crop. Inline, [8] reported a 20.3% higher productivity (yield advantage) of maize in intercropping compared to sole cropping systems. Similarly, [1] reported a 28% higher yield advantage in maize-common bean intercropping compared to monoculture, and a 23% yield advantage in maize-narrow leaf lupine intercropping over sole maize.

TABLE V. YIELD ADVANTAGE OF SORGHUM MUNG BEAN INTERCROP 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 x 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 x100%	2178.88	626.37	2805.25	-7.93	55.12
2:1 x 50%	2667.31	335.41	3002.72	-0.83	58.07
2:1 x 67%	3030.93	306.67	3337.6	9.28	62.28
2:1 x 100%	2880.41	290.07	3170.48	4.49	60.29
3:1 x 50%	2333.52	149.63	2483.15	-21.93	49.3
3:1 x 67%	2980.23	294.22	3274.45	7.53	61.55
3:1 x 100 %	2716.43	217.78	2934.21	-3.19	57.09
Sole	3027.83	1258.83	--------	-----	--------

CONCLUSION

The incorporation of legumes, such as mung bean, common bean, cowpea, and others, into the cereal cropping system helps to enhance soil fertility and mitigate climate change. Planting patterns and seed ratios of component crops play a role in the success or failure of intercropping. This study emphasizes the importance of optimizing seeding rates and planting patterns in sorghum-mung bean intercropping systems to achieve optimal productivity. The results suggest that intercropping sorghum with mung bean, particularly in a 1S:1M row arrangement with 50% mung bean population density, yields the highest productivity for both crops. This configuration provides a yield advantage over mono-cropping either crop. The study also recommends a mung bean population density of 50% (125,000 plants ha-1) for the region, as it strikes a balance between maximizing mung bean yield and maintaining sorghum productivity. The 1S:1M planting configuration is identified as the most effective for this intercropping system, improving spatial organization and resource utilization. This finding has implications for improving food security and sustainable agricultural practices in the region. Consequently, the recommended planting pattern for intercropping sorghum with mung beans in Lasta district is 1S:1M with a mung bean population density of 50% (125,000 plants ha^{-1}). The 1S:1M row arrangement is recommended to achieve optimal compatibility and yield productivity in this intercropping system. The results of this study indicate that a 1S:1M planting pattern with 50% mung bean population density is recommended for farmers in Lasta district. This approach is expected to increase the productivity of both crops, improve soil fertility and strengthen food security in the region. Adoption of the recommended seed rates and planting patterns is expected to result in increased crop yields and resource efficiency, thereby contributing to improved food security and sustainable agricultural practices. Study the long-term effects of intercropping on soil health and nutrient cycling, determination of planting date on the added (mung bean) crop as well as the scalability of these practices across different agro-ecological zones in Ethiopia is important in the future to ensure a sustainable future of the cropping system in the region.

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