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Response of Yield and Competition Indices to Row Configuration and Additive Series Intercropping in Sorghum (Sorghum Bicolor L.) Mung Bean (Vigna Radiata L.) Intercropping In Semi-Arid Area of Wag-Himira Zone, Ethiopia

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BAHIR DAR UNIVERSITY

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GRADUATE PROGRAM

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M.Sc. thesis

By

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M.Sc. Thesis

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THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (M.Sc.) IN AGRONOMY

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THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by Mr. Fentaw Asres entitled Response of Yield and Competition Indices to Row Configuration and Additive Series Intercropping in Sorghum (*Sorghum bicolor* L.)-Mung Bean (*Vigna radiata* L.) Intercropping in Semi-Arid Area of Wag Hemira Zone, Ethiopia. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in Agronomy.

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DECLARATION

This is to certify that this thesis entitled "**Response of Yield and Competition Indices to Row Configuration and Additive Series Intercropping in Sorghum (*sorghum bicolor* L.)-Mung Bean (*vigna radiata* L.) Intercropping in Semi-Arid Area of Wag Hemira Zone, Ethiopia**". Submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in **"Agronomy"** to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Fentaw Asres** (BDU, ID 1500869 PR) is an authentic work carried out by him under our guidance. The matter embodied in this thesis work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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Yayeh Bitew (PhD) Signature: _____Date May 30/2024

Name of Supervisor

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DEDICATION

To all Ethiopian who lost their life due to political disagreement particularly in Amhra Regional State

ABBREVIATIONS AND ACRONOMY

ATER	Area Time Equivalent Ratio
CIMMYT	Centro International de Mejoramiento de Maíz y Trigo
CR	Competitive Ratio
HSD	Turkey’s studentized Range Test
MASL	Meter above Sea Level
MAI	Monetary Advantage Index
MOARD	Ministry of Agriculture and Development
MRR	Marginal Rate of Return
RCBD	Randomized Complete Block Design
SWAO	Sekota Woreda Agricultural Office

Response of Yield and Competition Indices to Row Configuration and Additive Series Intercropping in Sorghum (*Sorghum bicolor l.*) Mung Bean (*Vigna radiata l.*) Intercropping IN SEMI-Arid area of Wag Hemira zone, Ethiopia

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ABSTRACT

Sorghum (Sorghum bicolor l.) is the main crop, and mung bean is the supplementary crop in the sorghum-mung bean intercropping system commonly practiced in the semi-arid region of Wag Hemira Zone, Ethiopia. However, the optimal row arrangement and seed proportions for this intercropping system have not been thoroughly investigated. Therefore, this experiment was conducted in 2023 at the Aybra main research site in the semi-arid area of Wag Hemira Zone, Ethiopia, to determine the optimum level of mung bean seed proportion and the proper sorghum-mung bean row configuration to achieve maximum productivity of the component crops and profitability of the overall sorghum-mung bean additive series intercropping system. A 3 x 4 factorial arrangement in RCBD design consisting of fourteen treatments including sole sorghum and mung bean as a check. The treatments consists of three seed proportions (%) of mung bean from the recommended practice (200%, 100%, and 67%) and four sorghum (S)-mung bean (M) row configurations (ratios) (1S:1M, 2S:1M, 1S:2M and 3S:1M) . Data on the agronomic attributes of the component crops in a mixture were collected in the field. Land equivalent ratio (LER), Area time equivalent ratio (ATER), monetary advantage index (MAI), competitive ratio (CR), and partial budget analysis were also calculated. These Data were analysed using SAS software. Most of the of agronomic attributes of the component crops in sorghum - mung bean intercropping were *significantly ($P<0.05$) affected by* row configuration and seed proportion of *mung bean and by their interaction. The highest grain yield of sorghum (3112.3 kg ha^{-1}) was found when 67% seed rate of* mung bean was planted in *1S:1M row ratio. The highest seed yield of mung bean (724.94 kg ha^{-1}) was found when 67% seed rate of* mung bean was planted in *1S:2M row ratio. The highest total LER (1.39), ATER (1.28) and MAI (57119,ETB ha^{-1}) were found when 67% seed rate of* mung bean was planted in *1S:1M row ratio. The highest net benefit* (207537.9 Birr ha^{-1}) *with acceptable range of marginal rate of return (2094.203) was obtained when 200% seed rate of* mung bean was planted in *1S:1M row ratio. Thus, based on economic benefit, intercropping of sorghum with mung bean in one to one row ratio with 67% 200% seed proportions of mung bean could be recommended for the study area. But for reliable results and recommendation, it is advisable to repeat the experiment at least for one more season over various locations.*

Keywords: sorghum, mung bean, LER, seed proportions, spatial arrangement, yield

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Chapter 1. INTRODUCTION

1.1.Background and Justification

Sorghum is a component of the Poaceae family's subfamily Andropogoneae and genus Sorghum (Clayton and Renvoize, 1986). The crop is grown for its grain, which is eaten, and its stalks, which are used as fodder and building materials in underdeveloped countries. In industrialized countries, grain, or sweet stem sorghum, is primarily utilized as animal feed for the production of sugar, syrup, and molasses (Doggett and Rao, 1995; Duncan, 1996). Every component of this plant is utilized to great effect by Ethiopian farmers at the household level (Amelework Beyene *et al.*, 2016). Sorghum is grown in Ethiopia in various agro-ecologies, particularly in moisture-stressed areas and severe food insecurity. It grows in 1,828,182.49 hectares in Ethiopia, producing 5,265,580.059 tons, a productivity of 2.88 ton ha^{-1} (Adugna Asfaw, 2007). In the Amhara region, it spans 259651.8 ha, producing 1,814,646.495 tons and a productivity of 2.828 ton ha^{-1} (CSA, 2022).

Among the most significant pulse crops, mung beans are produced globally in tropical and subtropical climates (Kumar *et al.*, 2012).This plant is grown primarily for its protein-rich edible seeds and fresh sprouts, as well as for use in stews, bread, and biscuits (Sehrawat *et al.*, 2013). Other benefits of mung beans include their ability to improve soil fertility, short growth cycles, low water needs, and utility in crop rotation and intercropping practices (Das *et al.*, 2014). Additionally, it is utilized as a green manure crop and as animal forage (Mohammed Ahmed *et al.*, 2017). It is regarded as Ethiopia's primary cash and commodity exchange crop (Ashenafi Nigussie, 2016). According to the CSA (2022), Ethiopia covers 49123.52 hectares of land with a production of 57,620.464 tons and productivity of 1.074 t ha^{-1} and it comprises 37809.61 hectares in the Amhara region with a production of 45,882.114 t and a productivity of 1.214 t ha^{-1}. Mung beans are a recent crop for Wag-hemira zone, as they are a low-land pulse that was only recently introduced to Ethiopia. However, up until 2022, there are no CSA data on the area coverage, production, and productivity in the Wag- hemira zone

Intercropping is the establishment of two or more crop species coexisting in the same field for all or a portion of their growing seasons (Dong *et al.*, 2018). In Sub-Saharan African nations, cereal legume intercropping is a popular farming technique that is used to improve soil fertility, increase food security, and make the most of limited farmland (Kinde Lamessa *et al*., 2016). Intercrop also increased output per unit area when compared to sole cropping through efficient resource use is a significant advantage of intercropping (Jalilian *et al*., 2017).

Intercropping, which also improves resource use, reduces soil erosion, boosts output stability, and reduces crop failure risks brought on by pests (Ashenafi Nigussie 2016). The best approach for feeding the expanding population is to increase food output by growing more crop varieties in the same field as intercropping (Gebremichael Abiy *et al.*, 2019). Intercropping is among the self-sustaining, diversified, low-input, and energy-efficient agricultural systems that are being promoted by many farmers, researchers, and policymakers as the best way to achieve agricultural sustainability (Jackson *et al.,* 2007). According to Layek *et al* (2014), several indices such as land equivalent ratio (LER), crop equivalent yield, competition ratio, intercropping advantage and monetary advantage index (MAI) have been suggested to describe competition and economic advantage of intercropping compared to monocropping. Mung bean is one of the most and early matured low-land pulse crop grown for income generation and home usage while sorghum is one of the top and most common cereal crop grown in wag hemira administrative before Sorghum, wheat, and barley (CSA, 2020). In wag-hemria, most farmers grow sorghum-mung bean intercrop sorghum as main crop and mung bean as additive crop in which mung bean is used as minor crop and sorghum as major crop. They grow those crops in an intercrop to without proper seed proportions and row configurations to overcome the shortage of arable land, for crop diversification, to get balanced diet, to improvement of soil fertility, as income source and to reduce crop failirity due to shortage of rainfall in the area (SWAO, 2023).

The percentage of seed added as additive in the main crop can determine the success or failure of intercropping as well as the degree of competition among component crops. The optimum seed proportion of component crops in intercropping systems depends on geographical location, as well as crop species involved. The percentage of seeds (plant density) is consequently an essential thing in figuring out the financial viability of an intercropping system (Daroish *et al.,* 2005). Ashenafi Nigussie (2016) reports yield variations due to seed proportions variation in haricot bean in maize-haricot bean intercrop and he recommended that

100% seed proportion of haricot bean from maize-haricot bean intercropping. Wondimkun Dikr (2022) also suggested 100% mung bean seed proportions for higher land equivalent ration and monetary advantage index in maize-mung bean intercropping. Similarly, Megersa Dinsa *et al.* (2020) reports the effect of seed proportions of soybean in maize-soybean intercrop and recommended 50% seed proportions of soybean for higher competition indexes and net benefits.

The other important management aspect in an intercrop is spatial row configuration which can improve radiation interception through more complete ground cover and determine whether an intercrop system will be advantageous or not with regard to yield gains (Nthabiseng *et al*., 2015). Row arrangements of component crops within row, improve the amount of light transmitted to the lower legume. Such arrangements can enhance legume yields and efficiency in cereal/legume intercrop systems (Nthabiseng *et al.*, 2015). Degu Temeche *et al. (*2022) reported highest net return and marginal return from one-row Sorghum alternated with two-row mung bean (1S : 2M) in sorghum-mung bean intercrops. Gashaw Melkie *et al.* (2020) reported high marginal return rate from 1 maize row alternatively with 2 row haricot bean arrangement in maize-haricot bean intercrop. Zeru Assefa *et al.* (2019) reported higher economic advantage from 2:1 sorghum- cowpea row arrangement at 50% cow pea seed proportions in sorghum-cowpea intercrop.

1.2.Statement of the Problem

In the smi-aried area of wag-hemria administrative zone, one of the most important crops is sorghum, followed by mung beans. To increase production per unit of land, it is crucial to determine the optimal seed proportions and spatial row arrangements. . Continuous sorghum mono-cropping, which grows the same crop for extended periods without the use of intercropping or crop rotation, is the predominant cropping system in the Wag-Himra region. This mono-cropping approach, coupled with poor agronomic practices, has led to low sorghum yields and declining soil fertility in the area. The region will no longer be capable of supporting crop production without the introduction of suitable soil fertility management practices such as integrating legume crops in intercropping and crop rotation with other crops.

The research hypothesis is that different seed proportions 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 is designed to test this hypothesis through field experiments using different treatment combinations of mung bean seed proportions and row arrangements of sorghum-mung bean intercropping. The expected outcomes of the study could include identifying the optimal seed proportions of mung bean and row arrangements of sorghum-mung bean intercrop 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 semi-arid area of wag hemira zone 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 seed proportions of mung bean when intercropped with sorghum and sorghum mung-bean intercrop row arrangement in in semi-arid area of wag hemira zone. As a result, intercropping sorghum and mung bean in appropriate seed proportions of mung bean and row arrangement is an excellent research topic in the study area. Furthermore, no research has been conducted in the study areas on the effects of seed proportions 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 seed proportions of mung bean and intercropping row ratio of mung bean with sorghum in the study area. Therefore, it is crucial to recommend better agronomic practices (optimum seed proportions and row configuration during intercrop) to improve production and productivity per unit area.

1.3. Objective of the Study

1.3.1. General objective

- To improve land use efficiency and crop productivity of the component crops in sorghum-mung bean additive serious intercropping system through various intercropping in the semi-arid regions of north-eastern Ethiopia

1.3.2. Specific objectives

- To determine the optimum seed proportion of mung bean and spatial row arrangement in sorghum-mung bean intercropping systems,
- To examine and select the highest land use efficiency through various competition indices in sorghum-mung bean intercropping systems, and
- To examine the profitability and the economic optimum seeding rates of mung bean and row ratio of sorghum-mung bean intercropping system

Chapter 2. LITERATURE REVIEW

2.1 sorghum

2.1.1 Description of sorghum

Sorghum belongs to the genus Sorghum and subfamily Andropogoneae of the Poaceae family (Clayton and Renvoize, 1986). The genus Sorghum has 25 types at the moment and is further subdivided into five subgenera: Eu-sorghum, Hetero-sorghum, Chaetosorghum, Parasorghum, and Stiposorghum (Dillon *et al*., 2007). With origins in Sub-Saharan Africa, sorghum (Sorghum bicolor L. Moench) is an important food crop in arid and semi-arid regions of the world. Sorghum is highly adaptable and may be grown in a wide range of conditions, including hot, dry, salty, and areas that are prone to flooding (Mohankumar *et al*., 2013). Originating in Africa, sorghum has a special climate adaptation there. It can withstand dry spells and periods of water logging (Kalhapure and Shete, 2013)

Ethiopia is most likely the country of origin for sorghum, which grows there in both wild and domesticated forms that are suited to a wide range of growing conditions. Therefore, for sorghum breeders worldwide, Ethiopia is a valuable source of diversified genetic material (Taye Tadesse *et al.*, 2008). Sorghum is planted under poor environmental conditions on marginal land. It is produced between sea level and more than 2,000 meters above sea level, and it adapts well to a broad range of temperatures and precipitation amounts (FAO, 2006).Sorghum is widely considered the most important staple food and feed product, followed by Sorghum and maize. Nearly 80% of Ethiopia's total sorghum production comes from the two primary producing regions, Oromiya and Amhara (CSA, 2014). East and West Hararge in Oromiya, North and South Wollo, South, North Gondar, and North Shoa in Amhara are the main sorghum-producing regions. Tigray and the Southern Nation and Nationality Peoples Region (SNNPR) contribute 11 and 4 percent of the nation's output, respectively (Ethiopian Sorghum Improvement project, 2013).High temperatures and scattered and infrequent rains (Adugna Asfaw, 2008). Human food, as well as feed for livestock and pigs, is made from grain sorghum. Both green and dry sorghum plants are used as nourishing fodder for dairy livestock. Additionally, grains are used to produce biofuels and alcoholic drinks. It is crucial in desert areas because it is heat and drought tolerant. Over 750 million people in the semi-arid tropical regions of Africa, Asia, and South America depend on it as their primary source of food (FAO, 2006). Sorghum is an abundant supply of minerals, proteins, carbohydrates, and vitamins B_1 and B_2 (Kalhapure and Shete 2013). It is primarily used in Ethiopia as a source of food for people and animals, for the production of local beverages, and for household buildings using the stalks (Amelework Beyene *et al.*, 2016). According to Vavilov (1951) and Doggett (Doggett H (1988), sorghum's based on geographically origins and early domestication seems to be in Africa. Sorghum (*Sorghum bicolor* (L) Moench) is believed to have originated in Ethiopia and been domesticated there. North-eastern Africa is where agricultural sorghum is first domesticated. Vavilov suggested Ethiopia as the sorghum's middle of origin because of the crop's wide variation (Vavilov, 1951). The diversity of morphological types grown in Ethiopia and the crop's extensive agro-ecological coverage are proof that Ethiopia, one of the founding nations of the sorghum, is endowed with a richness of genetic variation (Doggett, 1988). It is cultivated in Ethiopia at various altitudes and rainfall levels. Many of the hot, arid lowlands are used to produce sorghum, and some types are even grown up to 2,700 meters in elevation in the cooler, wetter highlands. In dry lowland regions with little rainfall, sorghum is usually the only crop is grown (Taye Tadesse and Gebisa Ejeta, 2019).

2.1.2. Environmental requirements of sorghum

Sorghum is a C4 grass with high photosynthetic efficiency. This plant needs long nights and short days prior to flowering or the onset of the reproductive cycle (Craufurd et al., 1999). Sorghum is usually grown on marginal soils in poor environmental conditions; the best soil types for sorghum growth are medium to deep black soils. The pH range of the soil in which it can be grown is from 5.0 to 8.5. It can withstand a broad range of temperatures and amounts of precipitation and grows between sea level and 2000 meters above sea level (FAO, 2006). It is the most preferred crop in arid and marginal areas that can offer a limited and irregular rainfall and high levels of drought resistance due to its inherent drought resistance and flexibility (Adugna Asfaw, 2008). For germination, the minimum temperature is 7°–10°C, while for growth, it is 15°C. The ideal range of temperatures for growth is 27–30°C. While sorghum can withstand higher temperatures than most cereals, mean temperatures above 26°C at the heading stage have a negative impact on yields. More leaves are laid down and panicle initiation is delayed by a higher temperature regime (Downes (1972).

2.1.3. Sorghum production and constraints in Ethiopia

Wortmann *et al*. (2006) state that drought; low soil fertility (deficiency in nutrients), shoot insects, quelea birds, Striga, and weeds are the primary obstacles to sorghum cultivation in East Africa. The proportional relevance of these restrictions varies between and within the various regions of the nation, despite the fact that they cause large losses in crop yield. Shoot fly, for instance, is said to be less of an issue in Mozambique but to be a major cause of grain losses in Ethiopia and Uganda (Wortmann et al. 2006). According to Gebretsadik Halefom et al. (2014), the two primary obstacles facing Ethiopia's northern and northeastern regions are the Striga weed and the country's drought. According to other research, moisture stress may be the main obstacle preventing grain encapsulation in Ethiopia. (Simane *et al*., 1998).Drought is one of the main issues influencing sorghum production globally. The lowland Ethiopian farmers rely solely on a rain-fed food production technique, which is notorious for producing subpar crops and yields. Low yields are mostly caused by moisture stress, poor soil fertility, Striga hermonthica, and restricted access to improved seeds and efficient production methods. The primary factor influencing sorghum productivity and production in the region is unpredictable rainfall patterns (Tadesse Getaw and Tesfahun Kassie 2001).

2.2. Mung Bean

For smallholder farmers in East Africa, the mung bean (Vigna radiata (L) Wilczek), also referred to as the dry bean or golden gram, is an important source of nutrition and revenue. Ethiopia is making good strides in the production of mung beans, which are an alternative pulse crop for crop rotation that improves soil fertility and one of the export pulse crops. According 22 the primary producing regions of mung beans are Benishangul Gumz (Asosa and Kamashi zones), Amhara (North Shewa, Oromia, Argoba Special wereda, and South Wolo zones and cover 21%), Oromia (Bale and Southwest Shewa zones cover 40% of area coverage), Gambella (Agnwak zone) SNNP 31%, and Benishangul Gumz. Because of a favorable regulatory framework that provides incentives and encourages production focused on the market.

According to farmers, the area covered and productivity of mung bean farming in Ethiopia is sporadically increasing. From 2310 tons in 2004 to 22719 tons yearly in 2013, Indonesia, Vietnam, and India receive the majority of Ethiopia's mung bean exports. MoT (2016).Mung beans can benefit lowland farmers both directly and indirectly. Because of its capacity to fix atmospheric nitrogen, short maturation period, low input requirements, low maintenance requirements, and drought tolerance, it can be included into a variety of cropping systems. Additionally, it greatly enhances soil fertility, Pricey, profitable, short-lived, cash crop, high nutritional content, opportunity crop, efficient use of water, economical, drought-resistant, utilizing soil moisture, and maintaining soil fertility (Pataczek et al., 2018). Due to its other advantages, such as boosting soil fertility, raising rural household income, creating job possibilities, varying diets, and boosting nutritional security, the crop has already become an important one. Shanmugasundaram (2009) stated that fixing atmospheric nitrogen and reducing soil nutrient depletion are excellent for arid land environments. It can be a versatile crop and a good source of high-quality protein for human consumption; leftovers after harvesting can be used into green manure or fodder (Pataczek *et al*., 2018). In addition to increasing a farmer's income from the sale of beans, mung bean production also lowers the amount of inputs needed on the field following cultivation.

2.2.1 Environmental requirement of mung bean

Mung beans, one of the most important pulse crops, are farmed worldwide in tropical and subtropical climates (Habte Umata, 2018). Warm-season crops, such as mung beans, grow best in temperatures between 27°C to 30°C, and it takes less than 90 days from sowing to maturity. Thus, summer is when the crop is usually cultivated. Seeds can be sown when the minimum temperature is higher than 15 °C. Fertile, sandy loam soils with good interior drainage and a pH of 6 to 7.2 are ideal for growing mung beans. Mung beans adapt to the day's length. Short days promote early flowering, while long days promote late flowering. In terms of heat and drought, mung beans accommodating

2.2.2. Mung bean production potential in Ethiopia.

Farmers in the Shewarobit North Shewa Amhara Ethiopia produce mung beans under irrigation during the belg season. Habte (2018) found that the greatest grain production of mung beans was 0.7868 ton ha^{-1}. These beans were harvested in west Hararge, Ethiopia, from the Borada research canter. The experimental data of Mohammed *et al*. (2015) indicates that Ethiopia produces 15,000-20,000 tons of mung beans a year. It has a high percentage of food security and is among the East African countries most hit by drought as a result of climate change. However, very little attention has been paid to the country's productivity growth despite its multifarious significance. Dry land areas have low agricultural yields because of their severe salinity and lack of water, which is causing a food scarcity. The mung bean, a short-season crop that can tolerate dry land conditions and fixe atmospheric nitrogen to prevent soil nutrient depletion, is becoming more and more popular. Moreover, the yield gap with respect to Asian countries suggests that smallholder productivity and output might increase, especially for green mung bean growers. Ethiopia has been endowed with a multitude of agro-ecological zones and a broad range of natural resources. It is recognized for being the origin and domestication site of various crop varieties. A vital commodity in Ethiopian smallholder agriculture, mung beans give small farm holdings a competitive edge by providing a replacement source of income.

2.2.3. Mung bean production and constraints in Ethiopia

Mung bean yields are greatly influenced by the amount and distribution of rainfall, with unpredictable rainfall being the main challenge faced by Ethiopian farmers when cultivating mung beans. Another significant barrier is the presence of diseases and pests that lower the yield and quality of mung beans. Apart from heat stress and salt, waterlogging and deficiency are the primary abiotic variables that restrict the growth, development, and yield characteristics of mung beans. Mung bean productivity strongly influences the amount of grain it produces, therefore in the absence of better management techniques and improved varieties; the crop's yield stays low. The primary causes were the usage of local kinds, insufficient or nonexistent use of inorganic fertilizer, and a dearth of improved high-yielding types. The challenges that crop production affected by climate change would be investigated, along with potential avenues for advancement in mung bean breeding and the application of improved management techniques (Wondimkun Dikr,2023). When compared to cereals, which have been chosen for high grain production under high input circumstances, the productivity of pulses, such mung beans, is quite low. Numerous biotic and abiotic stressors, including heavy metals, illnesses, pests, water stress, drought stress, and abnormally high temperatures, have a negative impact on mung bean productivity (Waniale *et al*., 2012; Das *et al*., 2014).

2.3. Concept and Principles of Intercropping

Intercropping is the process of growing two or more distinct crop species or varieties concurrently in various row configurations on the same piece of land (Katyayan, 2005). It can produce more than a monoculture because it uses resources like water, nutrients, and solar energy more efficiently (Kintl *et al*., 2019). Actually, the cropping system's value addition can ensure higher yields, more effective use of resources, and more revenue (Maitra *et al*., 2000; Manasa *et al*., 2018). By producing large crop yields and enhancing the environment through the use of biological processes to lessen anthropogenic inputs in agriculture, intercropping offers a potential route for ecological intensification (Bommarco *et al*., 2013). Basic ecological principles are observed in intercropping in the form of above- and Diversity, rivalry, and assistance for crop production below ground (Bedoussac *et al*., 2015). Numerous advantages of intercropping include improved grain yield, cheaper input costs from less fertilizer and pesticide use, yield stability and decreased risk of crop failures due to crop diversity, and profitable returns from grain legumes (Sahota, 2013). Additionally, compared to only of the respective crops, crops from an intercrop more effectively use various resources in a mixed crop system, producing greater production crops (Bedoussac et al., 2015; Li *et al*., 2006). An intercropping technique makes sure that the plant canopy covers a larger area of the soil; more transpiration occurs through the foliage, which might result in a cooler microclimate and make it easier to reduce soil temperature.

Plants in mixed crop systems employ available water in the form of soil moisture under stressing situations (Miao *et al*., 2016), and this microclimate has a positive effect on plant canopy height (Mao *et al*., 2012). Generally speaking, the goal of intercropping is to convert crop production or yield to dry matter by choosing morphologically distinct crops with distinct growth habits. This allows for the efficient use of resources (Lithourgidis *et al*., 2011). The performance and effectiveness of intercropping systems can be influenced by a variety of factors, including the selection of crops and cultivars, the amount sown, agronomic management (including water and nutrients), and the ability of crops to compete.

2.3.1. Cereal-legume intercrop

The establishment of sustainable food production systems requires the intercropping of grains and legumes, especially when the farmer uses little to no fertilizer and the soil contains very little organic matter (Bedoussac *et al*., 2015). Cereal crops deplete the soil of nutrients by absorbing them from the higher soil layers, according to studies by Ali *et al*. (2012) and Layek *et al*. (2014). By fixing atmospheric nitrogen (N) and lowering the quantity of rare soil nutrients held in the soil, legumes increase soil fertility (Meena *et al*., 2015a). Legumes' strong taproot structure aids in their uptake of nutrients from deeper soil layers (Jat *et al*., 2012). Intercropping cereals and legumes is a crucial part of subsistence farming in both developed and supplying a variety of food crops in developing nations, particularly in regions with limited irrigation resources (Tsubo *et al*., 2005). Cereal-legume intercropping has been demonstrated to decrease lodging (Anil *et al*., 1998), give constant yield (Lithourgidis *et al*., 2006), help control weeds, increase quality, extend availability, and conserve fodder (Papastylianou, 2004). It has also been found to conserve water and soil in specific landforms. To lessen the negative effects of moisture stress in years with low rainfall and excess moisture in years with high rainfall, legumes like soybean (Glycine max L.), groundnut (Arachis hypogaea L.), etc. can be interplanted with cereals like rice (Oryza sativa L.), maize (Zea mays L.), sorghum (Sorghum bicolor L.), pearl millet (Pennisetum typhoides L.), etc. Additionally, the various morphologies of they are able to fully benefit from the edaphic and climatic circumstances thanks to these crops. Because of their various roots and development patterns, varying nutritional requirements, length of cultivation, and other characteristics, they often have the capacity to function successfully even in stressful environments. Their intercropping techniques reduce competition for shared growth elements because soybeans are legumes and maize, sorghum, and pearl millet are cereals (Layek *et al*., 2014). However, because they are smaller than cereals in the intercropping system, legumes like soybeans and groundnuts may experience deficiencies in solar radiation, competition for nutrients, and competition for moisture in situations when there is a shortage of moisture (Maingi *et al*., 2001; Layek *et al*., 2014).

2.3.2. Spatial and temporal complementarity

Interspecific complementarity is the most complex reported process linking improved resource usage by intercrops to improved crop performance. According to this theory, crops have different strategies for locating and utilizing resources, which reduces interspecific competition (Bedoussac, 2009; Bedoussac *et al*., 2015). According to Justes *et al*. (2014), complementarity can be categorized as a temporal, spatial, or chemical partition. When there is a big gap in time between two plant species' needs, they can complement one another. When clover is planted in the spring alongside winter wheat as a cash crop, the growth of the legume does not inhibit the growth of the primary crop (Amosse et al., 2013). Stays underdeveloped throughout the intercropping phase and then speeds up its growth once the wheat is harvested. Due to spatial complementarity, the nutrient absorption process takes place at distinct locations based on rhizosphere interactions and the characteristics of the related plants. Root architecture and root depth, which control the depth of water or nutrient extraction, are the primary determinants of spatial complementarity (Hauggaard-Nielsen and Jensen, 2005). Vertical niche stratification is another term for spatial complementarity, which is attributed to depth-dependent extraction capability. Research on pea-barley intercrops (Hauggaard-Nielsen et al., 2001a) shown that the barley root systems use deeper soil layers when combined with the peas, supporting the evidence of such a spatial distribution. The term "chemical complementarity" describes the capacity of species to mobilize various nutrition chemical types. Chemical complementarity is used much less frequently to describe legumes' capacity to fix atmospheric nitrogen in a way that other species are unable to. Complementarity mechanisms should not be viewed as the outcome of plants' permanent and systematic behavior, but rather as a result of adaptive plant traits, such as root plasticity or nitrogen fixation (Bargaz et al., 2015), which are expressed in stressful situations (limited natural resource availability or significant competition with another species; Bedoussac et al., 2015; Fridley, 2002).

2.4. Types of intercrop

Raising two or more crops in close proximity on the same piece of land for a period of time is known as intercropping. According to Eskandari *et al*., (2009), intercropping allows for the geographical and temporal intensification of crops. Depending on the farmers' preferences and the appropriateness of the growing circumstances, this can involve a variety of combinations of annual and perennial crops. Furthermore, during all or part of the cultivation period, competition for resources occurs between the constituent species that are grown in intercropping.

2.4.1. Row intercropping

Row intercropping is the cultivation of one or more crops sown in regular rows, and the simultaneous cultivation of crops in rows or without rows. Row intercropping is a common practice aimed at maximizing and judicious use of resources and increasing productivity (Varma *et al.,* 2017).

2.4.2. Mixed intercropping

In mixed intercropping, two or more crops are grown together without a fixed row management. Sometimes it is also referred to as mixed culture (Von Cossel *et al.,* 2019). In pasture-based cropping systems, the intercropping of grasses and legumes is an ideal example of a mixed cropping (Gulwa *et al*., 2017). Mixed cropping is commonly seen to meet food and fodder needs when land resources are a limiting factor. Furthermore, a review article clearly describes perennial Polyculture as an agro ecological strategy in the cropping system with sufficient potential for the sustainable intensification of agricultural systems spatially and temporally (Weihuhn *et al.,* 2017).

2.4.3. Relay intercropping

Relay intercropping is the raising of two or more crops at the same time during part of the growing period of each. In this system, the second crop is sown when the first crop completes much of its life cycle and reaches the reproductive stage or approaches maturity but before harvest. Areas with limited time and soil moisture are more suitable for relay intercropping (Balde *et al.,* 2011). Before the previous crop is harvested, the next crop is sown and both crops remain in the field for a certain period of their cycle. However, the next crop yield less than normal sowing in the next crop and more seeds from the next crop are needed to get a good stand.

2.4.4. Sequential intercropping

According to Selvaggi *et al.* (2018), sequential intercropping is a type of multiple cropping where the second crop is planted after the first crop is harvested. One of the earliest methods of agriculture is sequential cultivation, much like other multiple cropping techniques. 12 successive cropping has always been essential for adjusting to shifting environmental circumstances throughout history (Petrie *et al.*, 2017). Sequential cropping can be utilized to lower the chance of total crop failure in a fluctuating environment, as well as for its possible stability and higher yields than monoculture. (Azam, 2003).Sequential intercropping methods have been shown to enhance agricultural system performance, hence mitigating the environmental impact of agricultural output, in addition to the direct benefits of agricultural production. Furthermore, although sequential cultivation has traditionally been implemented primarily in small farms and low-input production systems, it contains lessons on both structure and function that may also recommend more sustainable systems design of large scale agricultural activities (Francesco and Porter, 2016).

2.5 Agronomic Consideration in an intercropping

2.5.1. Crop choice

Yield gain is typically due to complementarity for resource capture, which occurs because crop species usually differ in one or more of the following traits: phenology, height, canopy structure; root distribution ability to symbiotically fix N from the soil; water consumption; ability to solubilize immobile soil phosphorus; and photosynthetic capacity (Gou *et al.*, 2018) and Tang *et al.*, 2021). Physiological variations in the mixture control the competition between component crops for growth limiting elements in intercropping. Choosing the right crop combination is essential in intercropping systems because plant competition can be minimised by combining crops and genotypes that use soil resources most efficiently, in addition to spatial organisation and seed proportions (plant density). According to research by Leary and Smith (2004), the best cultivar for monocropping may not be the best cultivar for mixed cropping due to microclimatic variation within crop combinations. Tamado Tana and Eshetu Mulatu (2002) reported that when groundnut cultivars were intercropped with sorghum cultivars, there was significant variation in yield and yield components between cultivars, suggesting that monocropping may not be the optimal situation for cultivar selection.

2.5.2. Plant Architecture

Plant architecture is a commonly used strategy that allows one member of the mix to capture sunlight that would otherwise be unavailable to the others for better utilisation of growth resources such as nutrients, light and moisture. Plant architectural responses to shade, such as a longer internode length and a larger specific leaf area, tend to result in the limiting light resource being captured better (Li *et al*., 2014). In the intercropping of maize with soybean, leaf area is usually reduced as a result of shading and reduced photosynthesis and biomass production (Fan *et al*., 2018). The architectural responses of wheat in wheat/maize relay strip intercropping increase its resource capture (Wang *et al*., 2017) and support the yield increase in border rows and in the intercrop as a whole. Plants in the inner rows of the strips in a strip intercrop typically do not differ in resource sourcing, growth, or yield from plants of the same species in a single crop, do not them usually exhibit architectural differences from single crops (Li *et al.,* 2020). In addition, two crops that differ in height, canopy, adaptation, and growth habits grow simultaneously with the least competition, greater yield stability, and better utilization of land resources (Kugbe *et al.*, 2018).

2.5.3. Plant population/density

Population density is an important factor in crop selection in cereal-legume intercropping systems since high densities can boost legume yields and productivity. The highest cowpea seed yield was obtained by planting sorghum-cowpea at a plant population density of 67%, according to Zeru Assefa *et al*. (2019). An additional study by Wondimkun (2022) found that the highest grain yield of maize was obtained when mung beans were planted at a plant population density of 100%. Additionally, he discovered that the largest number of seeds per pod was counted at 100% population density of the maize-bean intercrop, whereas the highest above-ground biomass was observed at 75% population density. Low plant population per unit area is the root cause of low yield (Jeyakumaran and Saren, 2007). In order to increase plant density, every crop in the mixture has its seeding rate set below its maximum rate. If the full rates of each crop were planted in the mix, none would do well. Determining how much to lower the seeding rate is the difficult part. Teshome Getu and colleagues (2015) conducted an experiment to investigate the impact of intercropping maize and soybean on yield and yield-related characteristics. The results showed that the soybean population that contained 75% maize had the maximum grain output (2.09 t/ha). According to their research, the highest yield of maize grain (7.33 t ha-1) was achieved when a 50% soybean population and 100% maize crop were combined. Research on varying pigeon pea plant densities in sorghum-pigeon pea has demonstrated the importance of plant density in crop output planting 50% corn and 100% sorghum In comparison to the lowest and greatest densities of 100% sorghum, 25% pigeon pea, and 100% sorghum, 75% pigeon pea, planting 100% sorghum and 50% pigeon pea yielded the highest total yield (Bilore et al., 1992).

2.5.4 Maturity dates

When two or more crops are grown together, the component crops should have different peak periods for growth resources (nutrient moisture and light). The greatest complementary effects and yield benefits are obtained when the component crops have different growing seasons, so that their main resource requirements occur at different times (Thayamini and Brintha, 2010). Adeniyan and Ayoola (2006) reported that maturity and growth habit of component crops were important determinants of productivity in maize-soybean intercrops. On the other hand, Reddy and Reddi (2007) reported that in maize-green gram intercropping system, the peak light requirement of maize was about 60 days after planting while green gram was ready for harvest. Khatri *et al*. (2014) intercropped maize with soybean, and intercropping systems were found to have a significant effect on physiological maturity. Plant maturity period was found to be significantly longer in sole maize system as compared to maize and soybean intercropping system.

2.6. Experimental designs in intercropping

The intercropping system's benefit or drawback in comparison to pure stands of the individual crops is determined by the proportionate row arrangement of the crop components (Yang *et al*., 2015). The intercropping system is intended to be an additive and replacement series, depending on how the rows are arranged and how much crop is planted. Intercrops are introduced to the base crop at 100% population in the additive series. The word "base crop" refers to the crop that is sown in a pure stand at 100% density, whereas the term "intercrop" refers to another crop. Intercrops are planted in the base crop's row space in an additive series. Occasionally, the base crop's planting geometry is changed to make room for intercrops (paired row planting, for instance). The When solo cropping, the percentage of intercrop (not base crop) typically stays below its ideal population. Since the intercrop has been added to the base crop up to 100% of its population in an additive sequence, the land equivalent ratio (LER) is typically seen to be greater than unity, indicating a yield advantage. Small landholders in developing nations typically favor yield advantage intercropping systems because they provide additional financial returns. The crops cultivated together in the replacement series of intercropping are referred to as component crops or intercrops. In this case, the other crop is substituted for one component crop. No crop is sown in the intercropping system's replacement series with its complete population as seeded in its respective only cutting. This system introduces the component crop in the spot where a certain percentage of the crop is sacrificed. Plant populations are occasionally enhanced relative to the densities used in pure stands in order to benefit from replacement series of intercropping in terms of yield (Baker *et al*., 1985). There is comparatively less species competition in such an intercropping system than in additive series.

2.7. Interaction Effect of Row Configuration and Mung Bean Population on Yield the Component crops

The density of plants has a significant impact on the number of branches per plant. Particularly when the vegetative period came to an end, the plants developed more branches. The number of branches per plant was larger in lower plant populations per ha than in higher plant population densities per ha. Plants used the resources with little rivalry at lower densities because interplant competition appeared to be minimal (Niazi, 2021). Variations in the haricot bean interpolation date affected the maize crop's capacity to compete (measured as leaf area and plant height). Reduced maize leaf area and height were the result of increased interspecies competition for growth limiting elements when legumes and maize were planted together. Interspecies competition was lessened and maize reached larger leaf areas in locations where mung bean and cereals planting was spaced apart. The number of branches per plant was significantly impacted by plant population density. More branches were present on the plants, especially as the vegetative period came to a conclusion. Compared to higher population density of plants/ha, lower plant population of plants/ha had more branches per plant. Interspecies competition was decreased and maize reached larger leaf areas when haricot bean and maize were planted at different times. When designing intercrops, one must take into account the plant's spatial layouts, planting rates, and maturity dates (Issahaku, 2010).

The number of branches per plant was significantly impacted by plant population density. More branches were present on the plants, especially as the vegetative period came to a conclusion. Compared to higher population density of plants/ha, lower plant population of plants/ha had more branches per plant. By utilizing the existing growth resources—such as light, heat, and water more efficiently, intercropping increases crop diversity in the cropping system and boosts yield on a particular plot of land. It accomplishes this by combining crops with varying rooting abilities, canopy arrangements, heights, and nutrient requirements, depending on how the component sole crops utilize those resources. (Issahaku, 2010). By combining a variety of crops with different root systems, canopy arrangements, heights, and nutrient requirements, and utilizing the available growth resources more efficiently than single crops do, intercropping broadens the cropping system's diversity and boosts yield on a given plot of land (Issahaku, 2010).

2.8. Interaction Effects of Row Configuration and Mung Bean Population on Competition Indices

Such systems should incorporate intercropping systems for sustainable tropical agriculture. It is anticipated that this system would withstand a variety of ecological and meteorological conditions. Achieving sustainable intercropping systems is essential in light of the shrinking amount of cultivable land, as it maximizes the effective use of growth resources that are available (Doubi et al., 2016).

2.9. Measuring Competition Indices in an Iintercropping

2.9.1. Land equivalent ratio (LER)

Land equivalent ratio is a relative land area required as sole crop to produce the same yield as an intercrop system. The advantage of inter crop is measured by major inter crop indices. LER is one of the most indices that indicate the benefit of planting two crops as an intercrop. LER is an indicator to determine the efficiency of intercropping. Land equivalent ratio (LER) is a common index used to measure the land productivity of intercropping systems (Iqbal *et al*., 2019). The value of LER greater than one indicates that the greater efficiency of land utilization in intercropping due to greater efficiency of resource utilization in intercropping (Mogiso and Nazib, 2020). LER measures 1.0, it tells us that the amount of land required for inter crop grown is the same as that for pure stand (*i.e*. there was no advantage to intercropping over pure stands). LERs above 1.0 show an advantage to intercropping while numbers below 1.0 show a disadvantage to intercropping. For example, an LER of 1.25 tells us that the yield produced in the total intercrop would have required 25% more land if planted in pure stands.

If the LER was 0.75 then we know the intercrop yield was only 75 % of that of the same amount of land that grow pure stands. 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.

Chapter 3. MATERIAL AND METHODS

3.1. Description of the Study Area

The experiment was carried out in Sekota district Wag Hemira administrative zone, in Sekoat dry land agricultural research center (Aybra main research site) closest to Mekelle main road, during 2023, between late June and November, under rain-fed conditions, on the representative sorghum and mung bean growing environments of sekota district (Figure 3.1). The area is located in Northeastern Ethiopia, 448 kilometers from Bahir-Dar (the capital of the regional state of Amhara Region) and 740 kilometers from Addis Ababa (the country's capital). It exists in the Wag Hemira Zone, in the Amhara region of northern Ethiopia. Unimodal rainfall pattern that covers the district from June to late August or early September. The district's agro ecology ranges from Woyna Dega (midlands) to Kola (lowlands). The research location is located at an altitude of 1915 meters above sea level and has geographic coordinates of 79^0 01, 08, E" N latitude and 12^0, 43, 38, NE longitude. During the cropping season the annual rainfall was 678.1 mm and the maximum and minimum air temperatures at the location were 27.30 ^{0}C and 12.70 ^{0}C, respectively (Figure 3.2) The most common cropping system are sole cropping, mixing cropping without specific row arrangement, improper seed proportions of the additive crop and the main crop, crop rotation without adhering to the legume cereal principle, and the crops cultivated in the area (district) are sorghum (*Sorghum bicolor*), Sorghum *(Eragrostis Sorghum (zucc.)*) (Trotter), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L) and *Triticum turgidum*) haricot bean, mung bean, faba bean are also some pules crops grown the study area (SWAO, 2023).

Before planting, composite soil samples were collected using an auger from the 0–20 cm depth. The composite samples were sampled by combining 20 subsamples taken from each experimental site using a zigzag sampling method. The disturbed composite soil samples were air-dried, mixed well and passed through a 2 mm sieve for all parameters that were determined except for total nitrogen and organic carbon, which passed through a 0.5 mm sieve. The composited sample was taken to determine soil texture, soil pH, organic carbon, total nitrogen, available phosphorus. The soil particle size distribution was analyzed via the hydrometer method (Bouyoucos, 1962). The soil pH was measured at a 1:2.5 (soil-to-water) ratio using a glass calomel combination electrode (Van Reeuwijk, 1991). Soil organic carbon was determined following the wet digestion method (Walkley and Black, 1934). Total nitrogen was analyzed using the Kjeldahl method. Available P was determined by Olsen's method (Olsen *et al*., 1954).

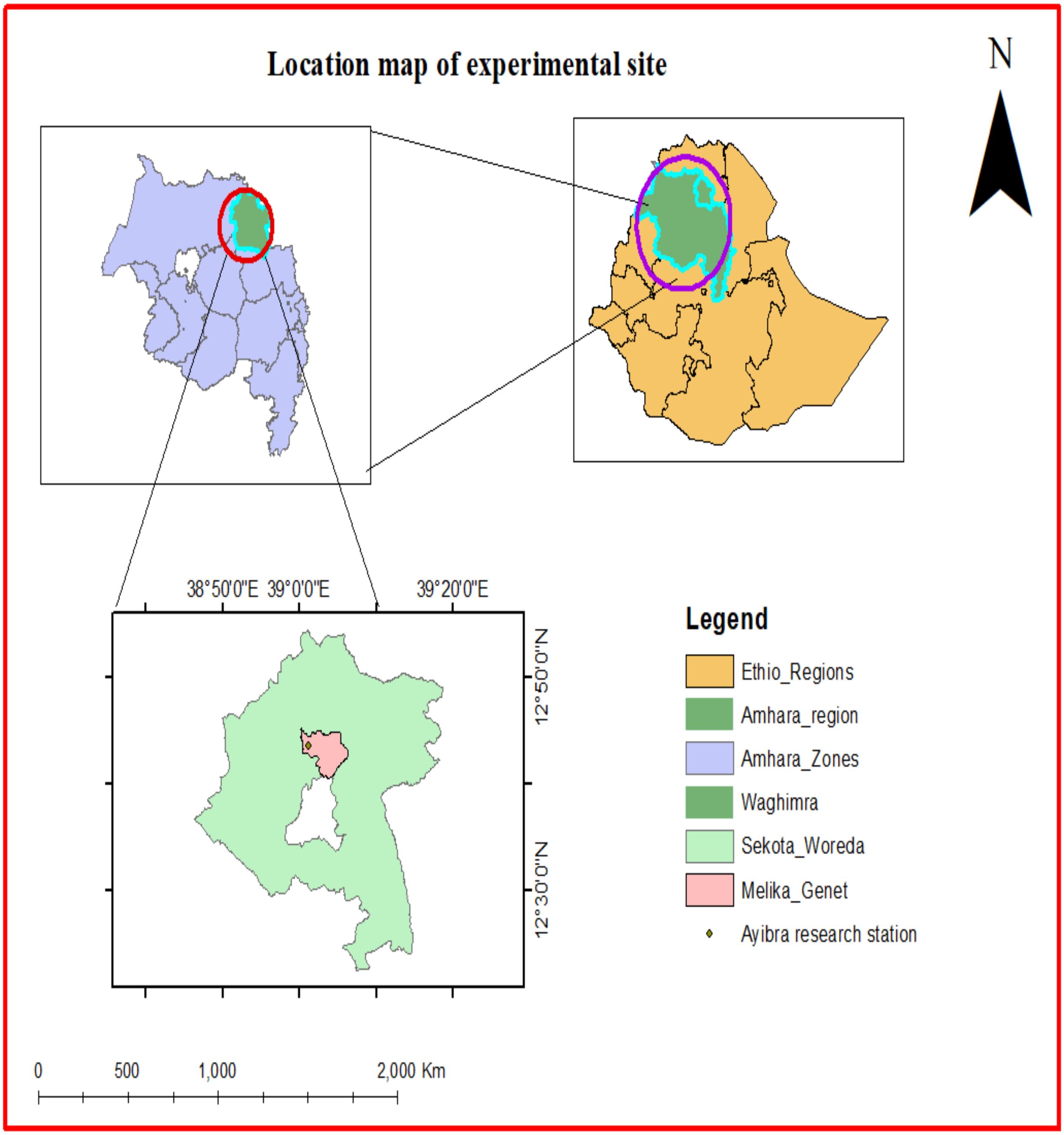

Figure 3. 1 Location map of the study area

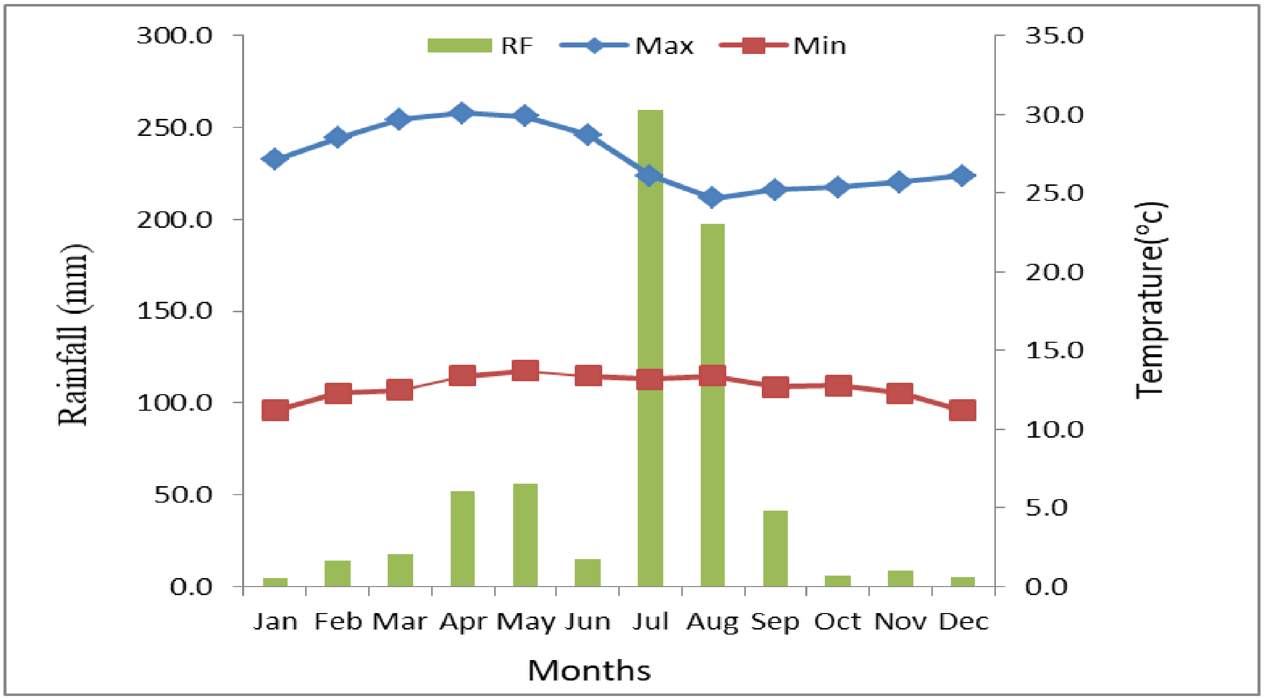

Figure 3. 2. Annual climate data of the study site

Table 3. 1. Physico-chemical properties of the soil during the study at Sekoat dry Land Agriculture Research Center (SDARC) main research site (Aybra) in 2023.

Soil properties	**Value**	**Rating**	**Sources**
pH (1:2.5 soil water ratio)	6.31	Slightly acidic	(Tekalgn, 1991)
OC %	0.487	Low	(Tekalign, 1991)
OM %	0.840	Low	(Tekalign, 1991)
TN %	0.029	Very low	(Tekalgn, 1991)
Available P ppm	23.23	High	(Olsen *et al.*, 1954)
Soil texture	Value in %	Class	
Sand	71	Sandy loam	USDA
Clay	12		
Silt	17		

Where OC=organic carbon, OM= organic matter, TN= total available nitrogen and P ppm=Available phosphors in ppm

3. 2. Experimental Materials

The study's primary crop was a sorghum type called Melkam, which matures early. The variety melkam has been acknowledged and advocated as a high yielding and early maturing crop variety in Wag hemira administrative zone (Abebe Assefa *et al.,* 2020). The companion crop in the additive series was the mung bean variety Rasa (N-26), which is released by MARC in 2011. The two crop species were chosen to intercrop with sorghum based on their ability to adapt to the environment and Genet kebede *et al*. (2002) (Abebe Assefa *et al.* 2020; Genet kebede *et al*., 2002)

Table 3. 2. Description of the experimental varieties (Melkam and Rassa)

Tested Variety	Years of Release	Days to maturity	Maturity Group	Alit(m)	RF(mm)	Released Institute	Yield on research	Yield on farm
Melkam	2009	118	Early matured	<1600	Up to 800	MARC (EIAR)	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 (EIAR)	0.8-1.5 t ha^{-1}	0.5-1 t $ha-^{1}$

Source: (MOARD, 2009; MOA, 2011)

3.3. Feld Experimental Treatment and Design

Three mung bean seed proportions (SP1, 200%, SP2, 100%, and SP3, 67%) and four sorghum-mung bean intercropping row configurations (1S:1M, 2S:1M, 1S:2M, and 3S:1M were combined and laid out in randomized complete block design (RCBD) with three replications in a plots size of 4.5 m length X 4 width (18m^2 plot size) and plots to plot were separated with 0.5m and from adjoining blocks 1 m respectively. Twelve intercropping and two sole cropping systems as check in additive series were used in the experiment. A standard recommendation of 100 kg NPSB (N18.9, P 37.7, S6.9, and 0.1% B) and 50 kg urea (46% N) ha^{-1} was utilized.

Table 3. 3. List of treatments and their arrangements

Treatment	Sorghum-mung bean row configuration	Mung bean Seed proportions	total treatment
1	1S:1M	200%	1S:1M X200%
2	2S:1M	200%	2S:1M X200%
3	1S:2M	200%	1S:2M X200%
4	3S:1M	200%	3S:1M X200%
5	1S:1M	100%	1S:1M X100%
6	2S:1M	100%	2S:1MX100%
7	1S:2M	100%	1S:2M X100%
8	3S:1M	100%	3S:1M X100%
9	1S:1M	67%	1S:1M X67%
10	2S:1M	67%	2S:1MX67%
11	1S:2M	67%	1S:2MX67%
12	3S:1M	67%	3S:1MX67%
13	Sole Sorghum	-	Sole Sorghumx100
14	Sole mung bean	100%	Sole mung beanx100

Where S= sorghum and M= mung bean

3.4. Field Experimental Procedures

The experimental land (plot) was prepared and uniformly labeled in May and late June 2023. Seeds of sorghum and mung bean for the experimental purpose were collected from Sekota Dry Land Agricultural Research center (SDARC). 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) 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 11, 2023 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 and thinned to one plant per hole was done for mung bean intercropped and sole plot. For both solitary sorghum and intercropped sorghum plots, a standard recommendation of 100 kg NPSB (18.9, 37.7, 6.9, and 0.1%) and 50 kg urea (46% N) ha^{-1} was utilized. A complete dose of NPSB was supplied when planting, while the other half of the nitrogen was top-dressed after the sorghum plant reached knee height (when it had produced 6–8 leaves). 100 kg of NPSB ha^{-1} was utilized and distributed completely for sole plots at the time of planting and mung bean was the only crop to get treatment, and no nitrogen fertilizer will be used for sole mung bean plots. 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 spar 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.

3. 5. Data Collection and Measurements.

3.5.2. Shoot and Yield Parameters of Sorghum

Plant Height (cm): plant height in centimeters was measured from ground level to the top of the spike, excluding the awns of 10 randomly taken plants from all harvestable rows of the plot, and recorded as the average height per plant.

Panicle length (cm): the panicle length was taken from the ten randomly sampled plants from the four central rows of each plot was measured in cm after taking the maturity date and averaged to represent the panicle length.

Above-ground dry biomass yield (kg ha^{-1}): It was recorded by harvesting from each net plot. It was sun-dried up to a constant weight, weighed, and then converted into kg ha-1. It was taken and measured from the net harvestable area of the net plot before threshing after sun drying for two weeks until it attained a constant weight

.

Thousand Seed weight (g): was determined by putting 1000 kernels into three replications and weighing them separately using sensitive balance and finally their averaged weight were taken.

Grain Yield per Plot (kg $plot^{-1}$): After harvesting, the seeds were threshed manually, cleaned, 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. Using the formula from Hellevang (1995), the adjusted yield will be computed.

Adjusted grain yield= (100-actual grain moisture content) / (100-stanadard grain moisture content) X grain yield per plot --- (1)

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

HI=Econmic yield/ biological yield X100 -- (2)

3.5.2. Shoot Parameters of Mung Bea

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 first by tag using plastic for the selected plants and then average was taken for analysis.

3.5.3. Yield Components and Yield of mung Bean

Pods per Plant: was counted from ten randomly selected mung bean plants at physiological maturity and the average was recorded for each plot.

Seeds per Pod: was recorded from ten randomly selected pods and the average was taken. Thousand Seed Weight (g): It was determined by putting 1000 seeds into three replications and weighing them using sensitive balance separately and finally the average weight was taken.

Above-ground dry biomass yield (kg ha^{-1}): It was recorded by harvesting from each net plot. It was sun-dried up to a constant weight, weighed, and then converted into kg ha^{-1}. It was taken and measured from the net harvestable area of the net plot before threshing after sun drying for two weeks until it attained a constant weight.

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

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

HI= (Economic yield)/ (Biological yield) X 100 ----------------------------- (3)

3.6. Intercrop System Productivity and Benefits in Sorghum Mung Bean Intercropping

3.6.1. Land equivalent ratio

The criterion for determining the advantage of mixed plantings is the land equivalent ratio (LER). According to Willey and Osiru (1972), it is a measure of complementarity and the value of unity is important. The LER was calculated as follows:

$$LER = \frac{YAB}{YA} + \frac{\mathrm{YBA}}{B} \quad \text{---} \ (4)$$

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) YA=Yield from sole planted crop A (sorghum) YB=Yield from sole planted crop B (mung bean). When the LER is greater than one, the intercropping favors the growth and yield of the species. In contrast, when LER is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures (Ofori and Stern (1987). Partial LER of sorghum and the partial LER of mung bean were first calculated to determine the total land equivalent ratio and to determine whether the main crop is benefited with the added crop or not.

3.6.2. Area time equivalent ratio (ATER)

ATER provides a 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 calculated by a formula developed by Hiebsch (1980) and calculated as

$$ATER = \frac{\mathrm{RYA\ X\ ta+RYB\ x\ tb}}{\mathrm{T}} \quad \text{---} \ (5)$$

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 one effect or no effect of intercropping.

3.6.3. Competitive ratio (CR)

Competitive ratio (CR) gives more desirable competitive ability for the crops and it is another way to know the degree with which one crop competes more than other for growth resource during intercrop. The CR represents simply the ratio of individual LERs of the two component crops and takes into account the proportion of the crops on which they are initially sown. The CR index was calculated by using the formula

CRAB = (LEA / LERB) (Zlb / Zab) while CRBA = (LERBA / LERB) (ZIb / ZIba) ------------ (6)

Where CRAB= competitive ratio of crop A (sorghum) on crop B (mung bean), LEA= land equivalent ration of crop A (partial land equivalent of crop A), LEB= land equivalent ratio of crop B, ZIb=sowing proportion of crop B (mung bean), Zab= sowing proportion of crop A (sorghum). If CR > one, indicates the base crop is competitor, while values < one implies the minor component crop is profusely suppressed the base crop or if CR cereal = 0, both crops are equally competitive, if CR cereal is positive then the cereal species is dominant, if CR cereal is negative then the cereal species is the dominated species.

3.6.4. 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 by the formula developed by (Willey 1979).

$\mathrm{MAI} = \text{the value of the intercrop X}(\mathrm{LER} - 1)/\mathrm{LER}$. ------------------------------------- (7)

The positive value of MAI indicates visibility of the system. As the time changes, the price of the two crops also changes. Due to this, the prices were at the time of harvesting, particularly November. The price of sorghum and mung bean at the time of harvesting was 50 and 70 birr per kg on the local market at Aybra, sekota district (Personal observation and SWAO, 2023).

3.6.5 Sorghum equivalent yield (SEY)

It is the conversion of crop yields into one form that allows us to compare the crops grown under intercropping (De Wit, 1960). The total of intercrop sorghum yield and converted mung bean yield was used to compute sorghum equivalent yield **(**SEY), which was then compared to the sole crop sorghum yield. The conversion is done in the form of a sorghum equivalent yield by considering the mung bean yield and market price of sorghum and mung bean (Singh *et al*., 2009).

$$\mathrm{SEY} = \mathrm{SY} + \mathrm{MBY}\left(\frac{\mathrm{PMB}}{\mathrm{PS}}\right)$$

Where; SY and MBY represent grain yields of sorghum and mung bean in intercropping, respectively, PS is price of sorghum kg ha^{-1} and PMB is price of mung bean kg ha^{-1}

3.7. Data Analysis

Quantitative data of the component crops from the experimental field was entered into Microsoft office excel. Data analyses for the growth, yield, and yield component of the component crops were conducted using statistical Software (SAS, 2016). Before analysis, the data were checked for normal distribution following the Shapiro-Wilk test for normality. Data were analyzed with mung bean seed proportions and spatial sorghum-mung bean arrangement as fixed effects and replication as random effects. First, data analysis of the growth, yield, and yield component of the component crops in all treatments (14) was subjected to analysis of variance (ANOVA) following the single degree of freedom orthogonal contrasts method. When there were significant differences between treatments at any5and 1% probability level, mean separation was done using the Tukey-Kramer HSD test. However, if there was no significant difference ($P > 0.05$) between all treatments (14), the data analysis of the same data in 12 treatments (excluding the sole crops) was subjected to an analysis of variance (ANOVA) following normal procedure. Mean separation was done using the same test, when there were significant differences between treatments at any probability level difference ($P < 0.05$).

3.8. Partial Budget Technique

Prior to economic analysis, the actual biomass and grain yield was adjusted downward by 10% to equalize the experimental yields with farmers would expect to get from the same treatment. For each treatments the gross benefit (GB), total costs that vary (TCV), net benefit (NB), and the marginal rate of return (MRR) was analyzed separately. Gross benefit was calculated as the product of adjusted grain and stalk yields and the price per kilogram of grain and stalk of sorghum and the grain yield of mung bean with respective price in each treatment. The current price of 1 kg of sorghum grain and stalk were 50 and 5 ETB, respectively, whereas the price of 1 kg of mung bean was 70 birr. The total costs that varied among all the treatments were fertilizer purchase costs, labor cost, chemical cost, and seed costs in ETB ha^{-1}. All the cost was valued based on the current price of each items. The cost of fertilizer in the form of urea and NPS was 45 birr per kg, the cost of labor per day was 200 birr and the chemical cost per litter was 2200 birr. The Net benefits (NB) was calculated as the difference between the gross benefit (GB) and total variable cost (TVC) of each treatment in ETB ha^{-1}. The dominance analyses were carried out first by listing the treatments in increasing cost variation for identifies the economically preferable treatment. The dominated treatments were removed from the analysis of MRR (CIMMYT, 1988). For each pair of ranked treatments, a marginal rate of return (MRR) was calculated change in net benefit to change in total variable cost as:

MRR $= NB/TVC * 100$ -- (7)

The MRR% between any pair of non-dominated treatments denotes the return per row arrangement and seed. The recommendation of this research was supported by economic analysis for significant biological yields, which is the partial budget analysis based on (CIMMYT, 1988).

Chapter 4. RESULTS AND DISCUSSIONS

4.1. Effects Sorghum Seed Proportions of Mung Bean and Row Arrangement on Growth, Yield and Yield Components of Sorghum

4.1.1. Plant height

The analysis of variances showed that row configuration were significantly ($p < 0.05$) affect sorghum plant height but seed proportions of mung bean were not significantly ($p > 0.05$) affected sorghum plant height (Appendix Table 1).

Interaction effect were significantly ($p<0.05$) affect sorghum plant height (Appendix Table 1). The tallest mean plant height (220.1cm) of sorghum was recorded when 67% seed proportion of mung bean was intercropped with sorghum in 1S:2M while the lowest (121.7cm) was recorded in when 67% seed proportion of mung bean was intercropped with sorghum in 2S:1M (Table 4).

The analysis of variances showed that the main effects of row configuration and their interaction effect significantly ($p < 0.05$) affected sorghum plant height but seed proportions of mung bean did not significantly ($p > 0.05$) affect sorghum plant height (Appendix Table 1). The tallest mean plant height (220.1cm) of sorghum was recorded when 67% seed proportion of mung bean was intercropped with sorghum in 1S:2M while the lowest (121.7cm) was recorded in when 67% seed proportion of mung bean was intercropped with sorghum in 2S:1M (Table 4). Similar to the result, Adeniyan *et al*. (2007) plant height of maize was increased under maize with African yam intercrop. In agreement with this result, Belistie Lulie *et al*. (2016), reported that under maize/ common bean intercropping height of maize was influenced by intercropping maize-common bean and this may indicating that the percent of computation for growth factors. But contrasting with this Zeru Assefa *et al.* (2019) sorghum plant height were not significantly affected due to the interaction of row arrangement and seed proportions (row spacing of cowpea) in sorghum-cowpea intercrop. But contrasting with this Zeru Assefa *et al.* (2019) sorghum plant height were not significantly affected due to the interaction of row arrangement and seed proportions (row spacing of cowpea) in sorghum-cowpea intercrop. Contrasting with this Flagot Dinku *et al*. (2020) reported plant height of maize was not affected due to the difference in row variation at habru, Northeastern Ethiopia. Similarly to the result, Zeru Assefa *et al.* (2019) plant height of sorghum was not affected due to the variation in seed proportion (row spacing) of cow pea in sorghum-cowpea intercrop at habru district, northeastern Ethiopia. Also in line with these, with this result, Jibril Temesgen *et al.* (2015) reported that plant height of maize was not affected due to the difference in common bean seed proportions at Jimma.

4.1.2.Panicle length

The analysis of variance shows that the main effects of row arrangement significantly ($p < 0.05$) affected panicle length of sorghum but the main effect of mung bean seed proportion and the interaction effects did not significantly($p>0.05$) affected sorghum panicle length (Appendix Table 1). This may be due to the absences of sharing growth factors (light, soil, air) at the panicle stage of sorghum.

Table 4. 1. Interaction effect of mung bean seed proportion and sorghum mung bean row arrangement on sorghum plant height

Treatment		
SDP	RA	Ph (cm)
67%	1: 1	128.4^{de}
	2: 1	121.7^{e}
	1: 2	220.1^{a}
	3: 1	149.6^{cde}
100%	1: 1	181.6^{abc}
	2: 1	126.9^{e}
	1: 2	174.6^{bc}
	3: 1	155.2^{cde}
200%	1: 1	166.3^{bcd}
	2: 1	159.6^{cde}
	1: 2	130.1^{de}
	3: 1	203.8^{ab}
Sole Sorghum		159.6^{cde}
HSD (5%)		21.94
±SE		1.5
CV (%)		8.15

Where, RA, row arrangement ratio of sorghum-mung bean intercrop, SP, seed proportions of mung bean, Ph, plant height, * = significant at $P < 0.05$, HSD= Turkey's student zed Range Test, ±SE= standard error

4.2. Yield Components and Yield of sorghum under sorghum-mung bean intercrop

4.2.1. Above ground biomass of Sorghum

The analysis of variance revealed that spatial arrangement and the interaction between seed proportions of mung bean and spatial row arrangement significantly ($P<0.05$) affected above ground biomass of sorghum crops in a sorghum-mung bean intercropping system but seed proportions of mung bean did not significantly ($p>0.05$) affect above ground biomass of sorghum (Appendix Table 1). , the highest above ground biomass (8.51ton ha^{-1}) was recorded when 200% seed proportions of mung bean intercropping at 1S:1M spatial arrangement while the lowest above ground biomass (4.95 ton ha^{-1}) recorded when 67% seed proportions of mung bean intercropping at 2S:1M spatial arrangement of sorghum-mung bean intercropping (Table 4.2). Discuss he probable reason and add related works (the previous finding about the interaction effects of both factors).

Regarding to the seed proportions, reported in contrast by Wondimkun Dikr (2022) and he found that higher above ground biomass in 50% than 100% seed of maize-mung bean intercrop and also Zeru Assefa *et al.* (2019) reported higher above ground biomass in higher plant population of cowpea than the lowest plant populations.

4.2.2. Grain yield of sorghum

The analysis of variance revealed that spatial arrangement and the interaction effects significantly ($P<0.05$) affected grain yield of sorghum in sorghum-mung bean intercropping system but seed proportions of mung bean did not significantly ($p>0.05$) affect grain yield of sorghum (Appendix Table 1). This could be partly attributed to the two crops are computed for nutrient on the critical growth period of the tow crops. Similarly with this result, Degu Temeche *et al.,* (2022), in sorghum- mung bean intercrop and Egesa *et al*. (2016) in sorghum-cowpea intercrop reported significant variation in row variation in sorghum-mung bean and cow pea intercrop. Concerning seed proportions, contrasting with this result, Megersa Dinsa *et al.* (2020) and Wondimkun Dikr (2022) reported significant variation of maize yield as the variation in seed proportions of common bean in maize-mung bean intercrop. In the interaction analysis,

The highest grain yield of sorghum (3112.3 kg ha^{-1}) was recorded when 67% seed proportions of mung bean intercropping at 1S:1M spatial arrangement while the lowest sorghum grain yield (2146.0 kg ha^{-1}) recorded when 100% seed proportions of mung bean intercropping at 3S:1M spatial arrangement of sorghum-mung bean intercropping (Table 4.2).

4.2.3. Thousand-kernel weight of sorghum

Thousand-kernel weight was not significantly (P>0.05) affected by row arrangement of sorghum mung bean inter crop but it was significantly (P<0.05) affected by seed proportions of mung bean and the interaction of row arrangement and seed proportions (Appendix 1). This might be due to relative competition of available resources. The highest thousand kernel weight (27.8gr) was recorded when 100% mung bean seed proportion intercropping at 1S:2M spatial arrangement in sorghum--mung bean intercropping (Table 4.2). This result agreed with the findings of Belistie Lulie, (2016) who noted that hundred seed weight of maize was higher in sparsely populated plants than densely populated plants in maize/ haricot bean intercrops. Teshome Gutu *et al*. (2015) also reported that the highest thousand kernel weight of maize seed (243.88g) was obtained from maize intercropped with 40% of soybean population density while intercropping with 75% soybean population gave the lowest thousand kernel weight of maize seed (229.11g) in maize/soybean intercropping system.

4.2.4. Harvest Index of sorghum

Harvest index was not significantly (P>0.05) affected by seed proportions of mung bean while row arrangement of sorghum mung bean intercrop and the interaction of row arrangement and seed proportions significantly (p<0.05) affected harvest index of sorghum (Appendix 1).This indicating that converting efficiency of biological yield in to dry matters were affected due to the difference in row arrangement and interaction of row arrangement and seed proportions The results show that the highest harvest index (50.3%)) was recorded when 200% mung bean seed proportion intercropping at 2S:1M while the lowest (34.2) harvest index where calculated when 100% seed proportion of mung bean intercropping at 3S:1M spatial row arrangement in sorghum-mung bean intercropping (Table 4.2). Lower HI of sorghum under intercropping might be due to inter specific competition for growth resources, i.e., moisture, nutrients and light. In line with this, reported higher harvest index in 50% than 25% soybean seed proportions in maize-soybean intercrop was reported by Megersa Dinsa *et al.* (2020).

Table 4. 2: Interaction effect of mung bean seed proportion and sorghum mung bean row arrangement on sorghum yield and yield components

Treatment and statistics					
SDP	RA	BM (kgha^{-1})	TSW (gr)	GY (kg ha^{-1})	HI (%)
67%	1: 1	7751^{ab}	21.7^{bc}	3112.3.6^{ab}	40.5^{ab}
	2: 1	4950^{c}	22.0^{abc}	2140.8^{fg}	43.7^{ab}
	1: 2	6531^{abc}	17.3^{c}	1968^{fg}	33.5^{b}
	3: 1	6060^{bc}	27.3^{ab}	2396.8^{ef}	39.9^{ab}
100%	1: 1	7842^{ab}	27.5^{ab}	2541.6^{de}	32.5^{b}
	2: 1	6870^{abc}	26.3^{ab}	2828.3^{bcd}	41.2^{ab}
	1: 2	6072^{bc}	27.8^{a}	2455.4^{ef}	41.4^{ab}
	3: 1	6401^{abc}	25.5^{ab}	2046.1^{g}	34.2^{ab}
200%	1: 1	8510^{a}	27.3^{ab}	2895.3^{bc}	34.4^{ab}
	2: 1	5292^{c}	23.8^{ab}	2607.7^{cde}	50.2^{a}
	1: 2	5060c	27.0^{ab}	2071.4^{g}	41.3^{ab}
	3: 1	6400	24.5^{ab}	2187.4^{fg}	34.8^{ab}
Sole Sorghum		6075^{bc}	24.8^{ab}	3218.1^{a}	50.1^{a}
HSD (5%)		1262.9	3.29	181.87	9.07
±SE		0.89	1.1	0.82	3.1
CV (%)		11.58	7.88	4.33	13.52

Where, RA= sorghum mung bean row arrangement, SDP=seed proportions of mung bean, BM= above ground biomass, TSW=thousand seed weight, 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 *, and ** significance at 5 and 1% level of probability, HSD=Turkey's studentized Range Test, SE standard error

4.3. Response of Mung Bean for Different Seed Proportions and Row Arrangement

4.3.1. Plant height

The analysis of variance revealed that the height of mung bean was significantly ($p < 0.05$) affected by the main and the interaction effects of sorghum - mung bean row arrangement and seed proportions of mung bean (Appendix Table 2). The tallest plant height (37.0 cm) was recorded when 100% seed proportion of mung bean was intercropped with sorghum at a 2S:1M row configuration, while the lowest (19.2 cm) was found when 67% of mung bean seed proportions were intercropped with sorghum at a 3S:1M row configuration (Table 6). The difference in plant height could be attributed to either differences in seed proportions or nutrient competition during the early growth stage of mung beans, resulting in poor growth.

This finding is consistent with the studies conducted by Belistie Lulie *et al.* (2016) and Dereje Getahun *et al*. (2018) who reported variations in plant height due to row variations in maize-haricot intercropping. Additionally, Murad and Mohammad (2014) reported that the plant height of mung bean was significantly affected by row arrangement in sunflower-mung bean intercrop.

Table 4. 3. Interaction effect of row arrangement of sorghum-mung bean intercrop and seed proportions of mung bean on mung bean plant height

Treatment		
SDP	RA	Ph(cm)
67%	1: 1	26.5[b]
	2: 1	34.0[a]
	1: 2	19.20[c]
	3: 1	33.8[a]
100%	1: 1	26.7[bc]
	2: 1	37.0[a]
	1: 2	32.5[ab]
	3: 1	32.1[ab]
200%	1: 1	25.7[bc]
	2: 1	34.6[a]
	1: 2	32.7[ab]
	3: 1	31.8[ab]
Sole Mung bean		30.5[ab]
HSD (5%)		4.11
±SE		1.36
CV (%)		7.74

Where S= sorghum, M= mung bean, RA=row arrangement of sorghum mung bean ratio, SDP=seed proportions of mung bean, and C.V (%), coefficient of variation, SE=standard error of the mean, HSD =Turkey's studentized Range Test, SE standard error of the mean

4.4. Yield Components and Yield of Mung Bean

4.4.1. Number of branches per plant

Analysis of variance showed that branches per plant was significantly ($P<0.05$) affected by row arrangement of sorghum-mung bean intercrop and the interaction effects of seed proportions of mung bean and row arrangement of sorghum-mung bean but seed proportions of mung bean did not significantly ($p>0.05$) affected the number of branches per plant of mung bean (Appendix 2).

The maximum (4.5) and minimum (2.53) number of branches per plant were recorded when 200% seed proportion of mung bean was intercropped in 1S:2M row configuration and when 67% seed proportion of mung bean was intercropped with sorghum in 2S:1M row configuration (Table 4.4). This is probably due to the higher seed proportions of mung bean and there may be more competition between intercrops and between different parts of individual plants. Similarly, Enatalem Amanu *et al.* (2022) reported significant variation in the number of branches per plant in maize-mung bean intercrops at Melkassa and Fides. In contrast, Zeru Assefa *et al.* (20190) reported that the number of branches per plant was significantly affected by the proportion of cowpea seeds in sorghum-cowpea intercrop at Haribu North-West Ethiopia.

4.4.2. Number of pods per plant

Analysis of variance showed that the main and the interaction effects of seed proportion of mung bean and row arrangement of sorghum-mung bean intercrop had a significant ($P <0.05$) effect on the number of pods per plant of mung bean (Appendix Table 2). The maximum number of pods per plant (17.80) was found when 200% seed proportion of mung bean was planted in 1S:2M row arrangement and the lowest (8.13) number of pods per plant was obtained when 67% seed proportion of mung bean was planted in 3S:1M row configuration of sorghum-mung bean intercrop (Table 7)Similarly, Degu Temeche *et al.* (2022) in sorghum-mung bean intercrop; number of pods per plant was significantly affected by row arrangement in sorghum-mung bean intercrop. Megersa Dinsa *et al.* (2019) reported that number of pods per plant was significantly affected by planting density in maize-soybean intercrop. In contrast to this study, Murad and Mohammad (2014) reported that number of pod per plant were not significantly different by row arrangement in sunflower mung bean intercrop.

4.4.3. Number of seeds per pod

Analysis of variance showed that both the main and interaction effects of mung bean seed percentage and sorghum-mung bean intercrop row arrangement had a non-significant (P >0.05) effect on the number of seeds per pod of mung bean (Appendix Table 2). This may be due to the absence of nutrient calculation at the critical period of the two intercrop species due to the dissimilar nature of the two crops. This result was consistent with the result reported by Murad and Mohammad (2014), who reported that the number of seeds per pod was not significantly affected by row arrangement and population density in sorghum-mung bean intercrop. Megersa Dinsa *et al.* (2019) also reported that number of seed per pod was not significantly affected by plant population density in maize-soybean inter crop. However, in contrast to this study, Jibril Temesgen *et al.* (2015) found that number of seeds per pod was significantly affected by variation in plant population.

4.4.4. Thousand Seed Weight

Thousand seed weight of mung bean was significantly ($p < 0.05$) affected by the main effect of row arrangement and the interaction of seed proportion and row configuration but not significantly ($p > 0.05$) affected by the main effect of seed proportions of mung bean (Appendix Table 2). The highest thousand seed weight of mung bean (44.7gr) was recorded when 67% seed proportion of mung bean intercrop at 1S:2M row configuration of sorghum-mung bean, while the lowest (34.2 gr) thousand seed weight of mung bean was recorded when 67% seed proportion of mung bean at 3S:1M sorghum-mung bean intercrop (Table 4.4). Similarly, variation in cowpea seed due to variation in plant population and row arrangement of sorghum-cowpea intercrop was reported by Zeru Assefa *et al*. (2019) and also this result was in agreement with the result reported by Biruk Tesfaye (2007), here hundred seed weight was significantly ($P<0.05$) different in sorghum/cowpea and intercrop. Similarly, Zerihun Abebe (2011) reported that thousand seed weight of soybean was significantly ($P<0.05$) different in maize/soybean intercropping due to differences in row arrangement.

In line with this study, Wondimkun Dikr (2022) reported that thousand seed weight was significantly affected by spatial row arrangement of mung bean. Similarly, Mitiku Woldesenbet and Getachew Mekonnen (2017) also reported that thousand seed weight of common bean was not significantly affected by plant population density.

4.4.5. Above ground biomass

The analysis of variance showed that seed proportions of mung bean and row arrangement of sorghum-mung bean intercrop had a significant ($p < 0.05$) effect on above ground biomass of mung bean Furthermore, the interaction effects of seed proportions of mung bean and row arrangement of sorghum-mung bean intercrop had a significant ($p < 0.05$) effect on above ground biomass of mung bean (Appendix Table 2). The maximum (4433.3 kg ha^{-1}) mean above ground biomass was found when 67% seed proportion of mung bean intercrop with sorghum at 1S:1M row arrangement of sorghum-mung bean intercrop while the lowest (2200.0 kg ha^{-1}) above ground biomass was obtained when 200% seed proportion of mung bean intercrop with sorghum at 2S:1M row configuration (Table 4.4). This could be due to intra-specific competition for the available limited growth resources and due to excessive seed proportions of mung bean as overpopulation will affect biomass production due to the crowding effect. Similarly, Wondimkun Dikr (2022) reported that above-ground biomass was significantly affected by both the interaction of row configuration and plant population density. Similarly, Muktar Hussien *et al.* (2019) also reported that the above ground biomass of mung bean was significantly affected by the presence of different row arrangement in mung bean-sugarcane inter crop. Similarly, Megersa Dinsa *et al.* (2019) reported that above ground biomass of soybean was significantly affected by different plant population density in maize-soybean intercrop. Other research findings reported by Mitiku Woldesenbet and Getachew Mekonnen (2017) dry above ground biomass of common bean were significantly affected by plant population density in common bean-maize inter-crop.

4.4.6. Seed yield of mung bean

The analysis of variance indicated that the grain yield of mung bean was significantly ($P<0.05$) affected by the main effects of seed proportion of mung bean and row arrangement and by their interactions (Appendix Table 2). The maximum mean seed yield (724.94 kg ha^{-1}) of mung bean was obtained when 67% seed proportion of mung bean was intercropped in 1S:2 row configuration, while the lowest (255.46 kg ha^{-1}) seed yield of mung bean was found when 67% seed proportion of mung bean was intercropped in 3S:1M row arrangement (Table 4.4). This indicates that higher interspecific competition of the two crops (light, water and nutrients) was high and it implies that higher seed proportions of mung bean affected the yield of mung bean as plant population determines the successes and failures of an intercrop. Similar to this research result, Wondimkun Dikr (2022) reported that seed yield of mung bean was significantly affected by plant population density. Also, Megersa Dinsa *et al.* (2019) confirmed that soybean yield was significantly affected by plant population difference in soybean-maize intercrop. Teshome Gutu *et al.* (2015) also confirmed that grain yield of soybean were significantly affected by plant population difference in soybean-maize intercrop. However, this research result did not agree with Murad and Mohammad (2014) who reported that yield of mung bean was not significantly affected by the variation in row arrangement in sunflower-mung bean intercrop.

4.4.7. Harvest Index of mung bean

The analysis of variance showed that the main effects of seed percentage of mung bean and row arrangement and their interaction significantly ($p<0.05$) affected the harvest index of mung bean (Appendix Table 2). The highest mean harvest index of mung bean (29.5%) was obtained when 100% seed proportion of mung bean was intercropped with sorghum at 1S:1M row configuration, while the lowest (6.9%) harvest index of mung bean was found when 200% seed proportion of mung bean was intercropped at 1S:2M (Table 4.4). The highest harvest index obtained at the lowest population density could be that there was low competition at the lowest population density, resulting in higher harvest index. Similarly, a higher harvest index of soybean was reported by Megersa Dinsa *et al*. (2020) in 50% soybean seed proportions than 75% in maize-soybean intercrop. This result is in agreement with Teshome Gutu *et al.* (2015) who reported significant variation in harvest index due to variation in seed proportion of soybean under soybean-maize intercropping. Megersa Dinsa *et al*. (2019) also reported that harvest index of soybean was affected by population density in soybean-maize inter crop. However, this result is inconsistent with Mitiku Woldesenbet and Getachew Mekonnen (2017) that harvest index of common bean was not significantly affected by population density of common bean in common bean- rice intercrop. In line with this result, Gashaw Melkie *et al* (2020) reported significant difference in harvest index of common bean due to row variation in maize haricot bean inter-crop.

Table 4. 4. Interaction effect of mung bean seed proportion and sorghum mung bean row arrangement on mung yield and yield related parameters

Treatment								
SDP	RA	PB (no)	PPP (no)	SPP (no)	TSW (gr)	BM (kg ha^{-1})	SY (kg ha^{-1})	HI (%)
67%	1: 1	3.6^{ab}	9.8^{def}	10.67	41.8^{ab}	2666.7^{de}	586.5^{cd}	12.3^{fg}
	2: 1	2.5^{c}	12.6^{cd}	10.47	38.8^{ab}	2400.0^{de}	676.2^{bc}	21.5^{cd}
	1: 2	3.5^{abc}	10.6^{cde}	10.47	34.2^{b}	3200.0^{bcd}	724.9^{b}	25.8^{bc}
	3: 1	3.5^{abc}	13.1^{cd}	10.67	44.7^{a}	1500.0^{f}	255.5^{i}	11.7^{fg}
100%	1: 1	3.5^{bc}	10.5^{cde}	10.67	40.0^{ab}	2803.3^{de}	441.4^{fg}	29.5^{b}
	2: 1	2.8^{bc}	8.5^{ef}	10.80	40.9^{ab}	2400.0^{de}	578.7^{cde}	22.3^{cd}
	1: 2	2.8^{bc}	10.6^{cde}	10.87	37.7^{ab}	3666.7^{bc}	401.1^{gh}	14.2^{ef}
	3: 1	3.5^{bc}	13.6^{bc}	10.47	44.5^{a}	2200.0^{ef}	301.9^{hi}	12.3^{fg}
200%	1: 1	2.9^{bc}	17.3^{ab}	10.20	41.8^{ab}	2833.3^{de}	540.1^{def}	22.5^{bcd}
	2: 1	3.6^{ab}	6.6^{f}	10.40	38.5^{ab}	2566.7^{de}	439.4^{fg}	20.0^{cde}
	1: 2	2.7^{bc}	11.6^{cde}	11.30	40.3^{ab}	3766.7^{b}	457.6^{efg}	6.9^{g}
	3: 1	4.5^{a}	17.8^{a}	12.07	41.4^{ab}	2200.0^{ef}	404.4^{gh}	16.8^{def}
Sole		3.3^{bc}	11.5^{cde}	10.80	40.2^{ab}	2913.3^{cde}	1307.2^{a}	44.870^{a}
HSD (5%)		0.58	2.22	Ns	4.97	486.56	101.3	6.01
±SE		1.19	0.72	0.34	1.6	0.8.	0.44	1.3
CV (%)		10.18	10.77	5.72	7.06	9.49	7.65	11.74

Note; Bpp= braches per plant, PPp=pods per plant, Spp =seeds 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 5 and 1% level of probability, HSD= Turkey's studentized Range Test

4.5. Intercrop System Productivity and Benefits

4.5.1 Land equivalent ratio (LER)

Total LER was significantly (P<0.05) affected by the main effects of seed proportion of mung bean and spatial row arrangement of sorghum-mung bean intercrop and by their interaction (Append Table 3). The total LER for all combinations except 3S:1M X100%, 3S:1M X 200%

and 1S:2M X67% of mung bean seed proportion were greater than one but the magnitudes vary from pattern to pattern (Table 4.6). The value of LER above one indicates that the intercropped utilize the available resource efficiently than sole cropped. The maximum total LER (1.39) was recorded when 67% seed proportion of mung bean intercrop with sorghum at 1S:1M) row arrangement (Table 4.6). A total LER 1.39, 1.31, 1.32, and 1.299 and indicates that 29-39% additional land were required to produce the same yield as intercropped or the farmers save 39-29% land because of inter cropping. Similarly, Yayeh Bitew *et al* (2021) reported that 60- 99% land saved due to inter crop in maize- common bean intercrop, Wondimkun Dikr (2022) report an intercrop advantage in terms of LER and he concluded that up 76% land saved due to intercrop in maize-mung bean intercrop. Negasa Dangia *et al.* (2021) also reports intercrop advantage and they concluded that up 65% land saved due to maize-soybean intercrop. The minimum total LER (0.84) was found in the combinations of 1S:2M X 67% seed proportion of mung bean intercropped with sorghum (Table 4.6). This was probably due to lower seed proportion in efficient utilization of natural resources, i.e., moisture, nutrients and light. The result clearly showed that LER increased with the increase in planting density. The increase of LER in increasing with plant population may be due to the increase in yield of the crops which caused by the increased amount of plant population per unit area. In line with this finding, Ejigu Ejara *et al*. (2017) and Ashenafi Nigussie (2016) and Mogiso and Nazib (2020) reports higher total LER in 1:1 combinations of cereals legume inter crop. In line with these findings, Wondimkun Dikr (2022) reports that higher total LER in higher seed proportions than the lowest seed proportions of mung bean intercropped with maize. Also in line with this result, Yayeh Bitew *et al* (2014) reported that higher TLER in higher seed proportions of lupine with wheat than lower seed proportion of lupine (higher TLER in 75% than 25% seed proportions of lupine intercropping with 100% wheat).

4.5.2 Area time equivalent ratio (ATER)

Area time equivalent ratio was significantly ($P<0.05$) affected by seed proportion of mung bean and spatial row arrangement of sorghum mung bean inter crop (Append Table 3). The highest ATER were found (1.6) in 2S:1M sorghum mung bean row arrangement with 100% seed proportions of mung bean and the lowest (0.78) ATER value was from in the combinations of 3S:1M sorghum- mung bean row arrangement with 67% seed proportion of mung bean (Table 4.6). 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.

Similarly, highest ATER was reported by Yayeh Bitew (2015) in 1:1 maize-potato, Ali Khan and Akmal (2014) reported that higher ATER in 1:1 sunflower mung bean inter crop. This indicates that sorghum- mung beam intercropping were compatible and more efficient resource exploitation and greater overall production than sole crops and the remaining intercropping arrangements. A treatment that have ATER below one indicated the disadvantage of inter crop in this combinations. This indicating that optimum population density is better than the highest when intercropping with sorghum in the test location as the population density determine the successes and risky of an inter crop. Similarly with this, with this result, Yayeh Bitew *et al.* (2014) report higher ATER in 75% seed proportion of Lupine-wheat intercrop that 50% and 25% lupine-wheat intercrop.

4.5.3.Monitory advantage index (MAI)

Monitory advantage index (MAI) was significantly ($p<0.05$) affected by spatial row arrangement of sorghum-mung bean intercrop and seed proportions of mung bean (Append Table 3). In this research findings, the MAI value was ranged from (-34266 ETB ha^{-1}) to (57119 ETB $ha^{-1)}$. The highest economic benefit in terms of MAI (57119 ETB ha^{-1}) was obtained when 67% seed proportion of mung bean intercropped at in 1S:1M and the lowest (-34266 ETB ha^{-1}) were found when 67% seed proportion of mung bean intercrop at 3S:1M row arrangement of sorghum mung bean intercrop (Table 4.6). This may indicate that lowest seed proportions and lowest row ratio may affect the economic visibility of the system.

This result was in line with (Willey, 1979) indicating that the treatments that have highest total LER have the highest MAI and the lowest total LER have a negative MAI. Similarly, Ashenafi Nigussie (2016) in maize haricot bean inter crop, maximum MAI value were achieved in 1:1 maize haricot bean inert crop. Similarly to this findings, Yayeh Bitew et *al.* (2014) reports maximum MAI in 50% lupine inter crop with 100% wheat than 75% lupine with 100% wheat in wheat lupine intercrop. Also in line with this research findings, Megersa Dinsa *et al.* (2020) reports higher MAI was obtained at 50% soybean intercropping with maize than 75% and 100% soybean in maize soybean intercrop. In argument with this, higher MAI was reported by at lower seed proportions of mung bean in maize-mung bean intercrop by Wondimkun Dikr (2022). But contrasting with this, maximum MAI in 100% haricot bean intercrop with 1M: 1H (maize-haricot bean) was reported by Ashenafi Nigussie (2016).

4.5. 4. Competitive ratio (CR)

The analysis of variances presented in (Appendix table 3) indicating that CR was significantly ($p < 0.05$) affected by the interaction of spatial row arrangement and seed proration of mung bean. The highest CR (6.46) value were obtained in 1S:2MX200% seed proportions of mung bean and lowest (1.14) CR in 3S:1M X 67% seed proportion of mung bean (Table 4.6). . All over, the CR value of sorghum was higher than the CR value of mung bean in this study and indicated that sorghum was more competitive than mung bean in sorghum mung bean inter cropping and in all of the treatments (Table 4.6), the CR value were higher than unity indicating that inter cropping of sorghum with mung bean in the study area is productive than planting each alone. In line with this, Ashenafi Nigussie (2016) reported that maize were more competitive than haricot bean in maize- haricot bean inter crop and higher CR value in lower (25%) seed proportion of haricot bean than maximum (50,75and 100%) seed proportion of haricot bean in maize-haricot bean intercrop. Yirsaw Hunegnaw *et al.* (2022), reported that tef had higher CR value than lupine in tef-lupine inter crop. In line with this, Ali Khan and Akmal (2014) reported that CR value of sunflower were higher than mung bean in mung bean sunflower intercrop and they conclude that sunflower were more competitive than mung bean.

4.5.5. Sorghum equivalent yield (SEY)

The analysis of variances presented in (table 4.5) indicating that SEY was significantly ($p < 0.05$) affected by the interaction of spatial row arrangement and seed proration of mung bean. The highest SEY (3868kgh-^{1}) value was obtained in 1S:1MX200% seed proportions of mung bean and lowest (2579.9kgh-^{1}) SEY in 3S:1M X 100% seed proportion of mung bean and row arrangement of sorghum mung bean intercropping (Table 4.5).

Table 4. 5. Partial land equivalent, total land equivalent, area time equivalent, and monetary advantage of sorghum-mung bean row arrangement and seed proportions of mung bean

Treatments	PLE Sor	PLER Mg	TLER	ATER	MAI	SEY
1S:1 MX200%	0.89[ab]	0.41[b]	1.31[a]	1.20[ab]	47328[a]	3867.6a
1S:1M X100%	0.78[cd]	0.33[c]	1.27[b]	1.03[c]	20848[b]	3774.9a
1S:1M X67%	0.95[a]	0.44[b]	1.39[a]	1.28[a]	57119[a]	3351.8b
2S:1M X200%	0.81[c]	0.33[c]	1.14[b]	1.05[c]	24404[b]	2686.8f
2S:1M X100%	0.87[b]	0.44[b]	1.32[a]	1.20[ab]	48971[a]	3202.0bc
2S:1 MX67%	0.66[ef]	0.51[a]	1.18[b]	1.04[c]	31938[b]	2789.2ef
1S:2M X200%	0.64[ef]	0.30[c]	0.95[c]	0.87[d]	-9555[c]	3317.9b
1S:2M X100%	0.76[cd]	0.35[c]	1.11[b]	1.02[c]	19163[b]	3021.6cd
1S:2M X67%	0.61[f]	0.23[d]	0.84[d]	0.78[e]	-34266[e]	3009.5cd
3S:1M X200%	0.68[e]	0.19[d]	0.87[cd]	0.82[de]	-25660[de]	2965.3de
3S:1M X100%	0.63[ef]	0.30[c]	0.94[c]	0.86[ed]	-11528[cd]	2579.0f
3S:1M X67%	0.74[d]	0.55[a]	1.29[a]	1.15[b]	48618[a]	2758.2ef
13 Sole sorghum	0.75[d]	-	0.75[ed]	-	-52007.7[f]	3218.1bc
14 Sole mung bean	-	0.37[c]	0.37[f]	-	-155639.75[g]	--------
Mean	0.75	0.37	1.13	1.03	18115	3118.9
HSD (5%).	0.06	0.06	0.09	0.07	15045	65.22
C.V (%)	4.6	8.69	4.73	4.57	31.53	2.27
R2	0.93	0.93	0.94	0.94	0.94	0.9

Where S, sorghum PLER Sor=partial land equivalent of sorghum, PLERMg= partial land equivalent of mung bean, TLER=total land equivalent ratio, ATER=Area time equivalent ratio, MAI, Monetary advantage index, LSD= least significance differences, CV= coefficient of variation, **= significance at 1%level of probability

Table 4. 6. Interaction effect of sorghum mung bean row arrangement and seed proportions of mung bean on competitive ratio

Treatments	CR Sor	CR Mg	CR total
1S:1M X200%	0.87[cd]	0.44[b]	1.94[cd]
1S:1 XM100%	1.01[bc]	0.26[defg]	3.87[b]
1S:1 XM67%	1.46[a]	0.23[efg]	6.17[a]
2S:1 XM200%	1.00[bc]	0.27[def]	3.71[b]
2S:1 XM100%	0.88[cd]	0.43[b]	2.01[cd]
2S:1 XM67%	0.86[d]	0.40[bc]	2.15[cd]
1S:2 XM200%	1.03[b]	0.16[g]	6.46[a]
1S:2 XM100%	0.87[cd]	0.3[cdef]	2.86[bc]
1S:2 XM67%	0.46[f]	0.33[cde]	1.42[cd]
3S:1 XM200%	0.99[bcd]	0.2f[g]	5.82[a]
3S:1 XM100%	0.51[f]	0.36[bcd]	1.54[cd]
3S:1 XM67%	0.63[e]	0.56[a]	1.14[d]
Mean	0.88	0.33	3.26
HSD (5%).	0.12	0.09	1.38
C.V (%)	8.4	16.86	25.07
R2	0.94	0.85	0.88

Where S= sorghum, M= mung bean, CR sor=Competitive ration of sorghum, CRMg= Competitive ration of mung bean, Agg Sor= aggressivity of sorghum, Agg Mg=aggressivity of mung bean, LSD= least significance differences, CV= coefficient of variation, **= significance at 1% level of probability.

4.6. Partial Budget Analysis

A cost-benefit analysis was conducted to determine the relative economic returns of the treatments applied, using prevailing market prices for sorghum and mung bean. The yields of the experimental crops were adjusted downward by 10% to account for the variability in the level of management between a researcher and a farmer (CIMMYT, 1988). The price of sorghum and mung bean was obtained from the local market through personal communication with sorghum and mung bean producers and retailers in Sekota District, which was the nearest market to the study area. Gross benefit was estimated as the product of adjusted profit and sorghum straw yield (kg ha^{-1}) and only mung bean grain yield (kg ha^{-1}), as mung bean straw yield is not commonly used by farmers in the study area, multiplied by the current market price at harvest. The selling price of sorghum grain yield and mung bean seed yield at the time of harvest was 50 Birr kg-1 and 70 Birr kg^{-1}, respectively, and the price of sorghum stalk was 110 per "shekme" after converting the biomass of the stalk to shekme.

The net benefit was calculated by subtracting the total cost of production from the gross benefit. The cost of production includes: current cost of fertilizer; 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 200 Birr day^{-1} and the cost of karate chemical for mung bean to manage the flea beetle insect at seedling level was ½ L ha-1 in 1800 Birr L-1 and its cost was doubled as it sprayed two times. Dominant treatments were analysed by ordering the treatments in terms of increasing variable costs. A treatment is dominant if it has a higher cost but a lower net benefit than any previous treatment. Finally, the marginal rate of return (MRR) was calculated, which is the percentage change in net benefit over the change in total variable costs when moving from a lower cost treatment to a higher cost treatment. All treatments were ranked from highest to lowest in terms of profitability. This was achieved by dividing the total variable cost by the net benefit multiplied by 100.

The maximum net benefit (207537.9 Birr ha^{-1}) was recorded when 200% seed rate of mung bean intercrop at 1S:1M row arrangement followed by (187266.9 Birr ha^{-1}) 100% seed rate of mung bean intercrop at 1S:1M row arrangement respectively with a MRR of 2094.20 and 595.30% whereas the sole mung bean treatment produced the lowest net benefit (75152.3 ETB) ha-1. (Table…) In the intercropping system, the lowest net benefit (130530.4 Birr ha^{-1}) was recorded from 67% seed rate of mung bean planted in 2S:1M row arrangement. Except for the row arrangement and seed proportion of mung bean of 2:1(100%), 1:1(100%) and 1:1(200%), other row arrangements and seed proportions were dominant (Table 4.7).

Table 4. 7. Economic (net benefit) advantage of sorghum-mung bean intercrops than planting each alone

RA	SPP	GSBM	GSGY	GMV	TVCC	ABM	ASGY	AMY	GB	NEB	D	MRR
Sole Mg	100%	-	-	1307.18	7200	0	0	1176.462	82352.34	75152.34		
Sole Sor	100%	7978	3218.105	0	7290	7180.02	2896.295	0	180714.8	173424.8		109191.7
3S:1M	67%	6066	2397	255.46	8259.43	5459.04	2157.12	229.914	151245.2	142985.8	D	
3S:1M	100%	6399	2146	269.05	8365.2	5759.01	1931.49	242.145	142319.7	133954.5	D	
2S:1M	67%	4954	2174	301.85	8610.982	4458.96	1956.6	271.665	139141.4	130530.4	D	
3S:1M	200%	6399	2187	401.11	8685.52	5759.01	1968.66	360.999	152498	143812.5	D	
2S:M1	100%	6868	2828	457.64	8804.28	6181.02	2545.47	411.876	187009.9	178205.6		315.7154
2S:1M	200%	5294	2641	558.57	9284.606	4764.42	2376.9	502.713	177857	168572.4	D	
1S:1M	67%	7754	2542	441.44	10006.36	6978.96	2287.44	397.296	177077.5	167071.2	D	
1S:1M	100%	7840	2895	508.33	10326.4	7056	2605.77	457.497	197593.3	187266.9		595.3046
1S:1M	200%	8510	3112	642.6	11294.36	7659	2801.07	578.34	218832.3	207537.9		2094.203
1S:2M	67%	6529	2168	676.16	12373.7	5876.01	1951.2	608.544	169538.1	157164.4	D	
1S:2M	100%	6066	2455	578.7	13362.52	5459.04	2209.86	520.83	174246.3	160883.8	D	
1S:2M	200%	5064	2071	919.95	15299.28	4557.96	1864.26	827.955	173959.7	158660.4	D	

Where Mg= sole mung bean, Sor=sole sorghum, GSBM=gross sorghum biomass, GSGY=gross sorghum yield, GMV= gross mung bean, TVCC=total variable cost, ABM =adjusted biomass of sorghum, ASGY=adjusted grain yield of sorghum, AMY=adjusted mung bean yield, GB=gross benefit, NEB= net benefit, D= dominance, and MRR=marginal rate of retu

Chapter 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The growth and yield components of sorghum and mung bean were significantly affected by the interaction effect of seed proportion of mung bean and spatial arrangement in a sorghum-mung bean additive series intercropped system. The highest grain yield of sorghum (3112.3kg ha^{-1}) was obtained when a 67% seed proportion of mung bean was intercrop with sorghum at a 1:1 spatial arrangement and the maximum seed yield of mung bean was obtained when 67% seed proportion of mung bean intercrop with sorghum at 1:2 spatial row arrangement.

The highest total LER (1.39), ATER (1.28) and MAI (57119 $ETBha^{-1}$) was recorded from 67% seed proportion of mung bean intercropping at 1:1 sorghum-mung bean spatial row arrangement. The highest net benefit (207537.9 Birr ha^{-1}) andmarginal rate of return (2094.203%) were recorded from 200% seed rate of mung bean intercrop at 1S:1M row arrangement .Thus, it can be concluded that planting mung bean with 200% seed proportion of mung bean with sorghum at a 1S:1M spatial arrangement increased the production efficiency and profitability of the sorghum-mung bean intercrop in the Wag-hemira administrative zone.

5. 2. Recommendation

Planting mung bean with a 200% seed proportion in sorghum-mung bean- intercropping at 1S:1M spatial arrangement increased the production efficiency and profitability of the sorghum-mung bean intercropping system in the semi aired area of Wag-hemira zone Ethiopia.

However, based on this experiment, the following research gaps will be suggested. The effect of mung bean on soil fertility needs to be investigated as sorghum (the main crop) and mung bean (a supplementary crop) intercropping is the dominant cropping system in the study area. Furthermore, to make reliable and acceptable recommendation it is better to repeat this experiment across location and over seasons since this study was carried out in a one place and season.

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7. APPENDIX

Appendix 1. Mean square value of seed proportions of mung bean and sorghum mung bean row arrangement on sorghum phenology, yield and yield related traits

Treatments	DF	DsH	DsM	Ph	Pl	BM	TSW	GY	HI
RA	3	46.740^{ns}	4.32^{ns}	2662.33^{**}	16.86^{*}	$1.02e+07^{**}$	7.82^{ns}	775233^{**}	163.44^{*}
SPP	2	21.58^{ns}	12.33^{ns}	302.59^{ns}	4.47^{ns}	890655^{ns}	71.79^{**}	6087^{ns}	26.35^{*}
RA*SPP	6	47.65^{ns}	6.74^{ns}	3987.71^{**}	4.45^{ns}	1514012^{*}	27.50^{**}	252415^{**}	60.47^{ns}
Error	24	60.61	10.27	175.8	3.95	601404	4.36	57467	37.83
Total	35								
CV		10.52	3.05	8.3	9.62	11.97	8.4	9.71	15.77
Contrast with sole crop	38	39.11^{ns}	6.5^{ns}	2707.89^{**}	7.69^{**}	3461522^{**}	27.67^{**}	500546^{**}	103.92^{*}

Where RA= row arrangement of sorghum-mung bean inert crop, SPP seed proportions of mung bean, DF=degree of freedom, DsH=days to heading, Dsm,= days to maturity, Ph= plant height (cm), Pl= panicle length,, Bm= biomass (kg ha), TSW=thousand seed weight, GY= grain yield (kg ha), Hi= harvest index, CV= coefficient of variation

Appendix 2. Mean square value of sorghum mung bean row arrangement and seed proportions of mung bean on mung bean phenology, yield and yield related traits

Treatments	DF	DsF	DM	Ph	BPP	PP	Spp	Bm	TSW	SY	HI
AR	3	2.2^{ns}	9.22*	158.15^{**}	1.46^{**}	57.78^{**}	0.58^{ns}	289225^{*}	58.31^{**}	27563^{**}	49.81^{*}
SDP	2	1.03^{ns}	$0\ .27^{ns}$	41.08^{**}	0.28^{ns}	24.15^{**}	0.49^{ns}	1309086^{**}	3.21^{ns}	79936^{**}	115.14^{**}
RA*SPP	6	5.8^{ns}	2.47^{ns}	47.04^{**}	0.91^{**}	28.41^{**}	0.88^{ns}	2868197^{**}	15.14^{ns}	123067^{**}	138.09^{**}
Error	24	3.08	3	7.11	0.15	1.71	0.42	92669	9.86	5451	11.71
Total	35										
CV (5%)		4.41	2.02	8.76	11.8	11.2	6.07	10.61	7.81	14.07	18.09
Contrast with sole mung bean	38	3.7^{ns}	3.55^{ns}	69.90^{**}	0.87^{**}	32.68^{**}	0.67^{ns}	2010708^{**}	22.68^{*}	211564^{**}	288.8^{**}

Where RA= row arrangement of sorghum-mung bean inert crop, SDP seed proportions of mung bean, DF=degree of freedom, DsF=days to flowering, Dm,= days to maturity, Ph= plant height (cm), BPP= branch per plant, PP= pod per plant, spp= seed per pod, Bm= biomass (kg ha), TSW=thousand seed weight, Sy= seed yield (kg ha), Hi= harvest index, CV= coefficient of variation

Appendix Table 3. Mean square value of sorghum mung bean row arrangement and seed proportions of mung bean on some intercrop indexes

Treatments	DF	PLER Sor	PLER Mg	TLER	ATER	MAI	CR Sor	CR mg	CR total	Agg Sor	AggMg
RA	3	0.08^{**}	0.034^{**}	0.106**	0.15^{**}	$5.2e+07^{**}$	0.27^{**}	0.023^{**}	3.66^{**}	0.10^{**}	0.10^{**}
SPP	2	0.002^{ns}	0.47^{**}	0.065**	0.016^{**}	$8.5e+08^{**}$	0.08^{**}	0.039^{**}	13.59^{**}	0.24^{**}	0.24^{**}
RA XSPP	6	0.027^{**}	0.33^{**}	0.110**	0.06^{**}	$2.5e+09^{**}$	0.22^{**}	0.045^{**}	14.29^{**}	0.43^{**}	0.43^{**}
Error	22	0.001	0.004	0.01	0.0021	7.8e+07	0.005	0.003	0.66	0.007	0.007
Total	35										
CV (%)		4.63	9.14	8.03	4.53	32.1	8.19	17.04	24.98	13.13	13.13

Where RA= row arrangement of sorghum mung bean intercrop, Spp= seed proportions of mung bean, Df=degree of freedom, PLER Sor= partial land equivalent ratio of sorghum, PLERMg= partial land equivalent ratio of mung bean, TLER= total land equivalent ratio ratio, ATER= area time equivalent ratio, MAI=monetary advantage index, CR Sor= competitive ratio of sorghum, CR Mg= competitive ratio of mung bean, Agg Sor=aggressivity of sorghum and

8. BIOGRAPHY

The author, Fentaw Asres was born in 27 august 1977 in north Wollo zone at Kobo wereda (gobye) district in Amhara region, Ethiopia. He attended his elementary school at gobye primary school from 1984 to 1989. He completed his secondary and preparatory school education at Woldiya Secondary High School from 1995 to 1999. He joined Woreta TVET College of agriculture in 2001 for certificate, and completed his study with agriculture of Science in 29 June 2001. After his successful graduation, he was employed in Wag hemira zone development as assistance in July 2001 and served as development assistance for four year. In 2006, he joined kombolcha agricultural TVET to pressure his diploma in Agriculture, college and was employed in Wag hemira zone rural agricultural office for 2 years. In 22 march 2010 he employed at Sekota Dry Land Agricultural Research center and served as technical assistance for five year. In 2015, he joined Wollo University and completed his study with Bachelor of Science degree in plant science in June 2017. In 2023, he joined Bahir Dar University, college of agriculture and environmental science, school of post graduate programs to pursue his M.Sc. degree in agronomy.

Appendix Figure 1. Picture taken at the time of sowing of sorghum-mung bean intercropping at Sekota (Photo taken by the author, 2023)

Appendix Figure 2. Picture taken at the time of vegetative growth of sorghum-mung bean intercropping at Sekota (Photo taken by the author, 2024)

Appendix Figure 3. Picture taken at the time of vegetative growth of sorghum-mung bean intercropping at Sekota (Photo taken by the author, 2023)

Appendix Figure 4. Picture taken at the time of heading of sorghum-mung bean intercropping at Sekota (Photo taken by the author, 2024)

Appendix Figure 5. Picture taken at the time of maturity of sorghum-mung bean intercropping at Sekota (Photo taken by the author, 2024)

Appendix Figure 6. Picture taken at the time of harvesting of sorghum-mung bean intercropping at Sekota (Photo taken by the author, 2024)

Appendix Figure 7. Picture taken at the time of cleaning of sorghum-mung bean intercropping at Sekota (Photo taken by the author, 2024)