EFFECT OF PLANTING DENSITY OF LIMA BEAN (*Phaseolusl lunatus* L.) ON THE PERFORMANCE AND SYSTEM PRODUCTIVITY OF MAIZE (*Zea mays* L.)-LIMA BEAN INTERCROPPING IN SOUTH WESTERN ETHIOPIA

M.Sc THESIS

JIHAD HUSEN MOHAMMED

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M.Sc THESIS

Submitted to Jimma University College of Agriculture and Veterinary Medicine Department of Horticulture and Plant Sciences in Partial Fulfillment of the Requirements for the Degree of Master of Science in Agronomy

Major Advisor: Amsalu Nebiyu (Ph.D)

Co-Advisor: Merkeb Getachew (Ph.D)

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MSc THESIS APPROVAL SHEET

We, the undersigned, member of the Board of Examiners of the final open defense by **Jihad Husen** have read and evaluated his/her thesis entitled **"Effect of Planting Density of Lima Bean (Phaseolusl Lunatus L.) On the Performance and System Productivity of Maize (Zea Mays L.)-Lima Bean Intercropping in South West Ethiopia"** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Master of Science in **Agronomy**

Dr Fikadu Negese Name of the Chairperson	---------------------------- Signature	14/06/2024 Date
Dr Amsalu Nebiyu Name of Major Advisor	---------------------------- Signature	14/6/24 Date
Dr Zeleke Wondimu Name of the Internal Examiner	---------------------------- Signature	14 June 2024 Date
Dr Tolera Abera Name of the External Examiner	---------------------------- Signature	------------------ Date

DEDICATION

I dedicate this thesis to my beloved wife Juwara Abdulkadir, My Son Ihlam, and my friend Mohammed Jibril for nursing me with affection, and love and for their dedicated partnership in the success of my life. May our creator give them long life!

STATEMENT OF THE AUTHOR

First I declare this Thesis is a result of my genuine work and that I have duly acknowledged all source of materials used in writing it. This Thesis has been submitted in partial Fulfillment of MSc. Degree at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to users under rule of the Library. I seriously declare that this Thesis was not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Request for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by head of the major department of dean of the school of graduate studies when in his or her judgment the proposed use of the material is for scholarly interest. In all other instance, however permission must be obtained from the author.

Name: **Jihad Husen**

Signature: ________________

Place **Jimma University**

Date of submission: -----------

BIOGRAPHICAL SKETCH

The author, Jihad Husen Mohammed, was born in Bure Woreda, Ilubabor Zone in 1994. He pursued his primary education at Obomiriga Primary School before moving on to Sibo Secondary School to complete his secondary school. After successfully passing the Ethiopian Higher Education Entrance Qualification Examination (EHEEQE) in 2008, he joined Bako ATVET collage and graduated with diploma in plant science in October 2009. After working for three years in Selle Nono woreda Agriculture Office as development agent (DA), he joined Jimma University and graduated with a BSc degree in Plant Sciences in June 2016. Then after working for four years, in Land use and administration office as an expert he joined the Post Graduate Programs of Jimma University in November 2020 to pursue a study leading to the degree of Master of Science in Agronomy**.**

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ABBREVIATION AND ACRONYMS

ANOVA	Analysis of Variance
BNF	Biological nitrogen fixation
CEC	Cation Exchangeable Capacity
CIMMTY	International Maize and Wheat Improvement Center
CSA	Central Statics Agency
ETB	Ethiopian Birr
FAOSTAT	FAO database of agricultural statistics
GLM	General Linear Model
LCG	Lowest Concentration of Gelling
LER	Land equivalent ratio
LSD	Least significance difference
MEY	Maize equivalent yield
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System software
UK	United Kingdom
YiLb	Yield of intercrop maize
YiM	Yield of intercrop lima bean

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

LIST OF APPENDICES

FIGURE OF APPENDICES

Effect of Planting Density of Lima Bean (*Phaseolusl lunatus* L.) on the Performance and System Productivity of Maize (*Zea mays* L.)-Lima Bean Intercropping in Southwestern Ethiopia

ABSTRACT

*The gradual decrease in land holdings for food production is alarming over time to meet the increasing food demand of the increasing population all over the world particularly in developing nations like Ethiopia. Cultivating multiple crops together (intercropping) is one of the feasible options to maximize crop yields per unit area. The objective of this study was to determine the optimum planting density of Lima bean when intercropped with maize for greater yield and system productivity of the associated crops. The experiment was conducted at two sites (Seka and Dimtu) of Jimma zone, Southwestern Ethiopia in the 2022/23 cropping season. The experiment consisted of treatments: sole maize (T_1), sole Lima bean (T_2), Lima bean intra-row spaced at 35cm and intercropped with maize (T_3), Lima bean intra-row spaced at 50cm and intercropped with maize (T_4), Lima bean intra-row spaced at 65cm and intercropped with maize (T_5). The analysis of variance showed that the effects of component population densities on phenology of maize and Lima beans were statistically not significant ($p>0.05$) except only for days to physiological maturity ($P<0.05$) at Dimtu site. Intercropping treatments showed significant differences on yield performance of maize and lima bean. Among the intercropping systems lima bean intra-row spaced at 65cm and intercropped with maize gave the highest grain yield of maize (4.83 and 4.*53 t ha^{-1}), *Land equivalent ratio (1.68 and 1.63), maize equivalent yield (MEY: 7.95 and 8.0* t ha^{-1}*) and lima bean equivalent yield (LBEY: 4.40 and 4.3* t ha^{-1}*)* at *Seka and Dimtu sites, respectively. The intercropping maize with lima bean was advantageous than sole cropping of each crop. The findings showed that intercropping maize and Lima beans provided more yield per unit area. Therefore, planting lima bean with a density 20,512ha^{-1} at spacing of 75*65cm could be recommended for intercropping with maize in the target areas, spacing of 75*50cm also could be recommended as an option.*

Key Words: *Maize, lima bean, intercropping, system productivity, population density.*

1. INTRODUCTION

The fixed and timely decreasing land for food production is becoming more important to raise crop productivity in order to meet the increasing food requirements of an increasing population all over the world (Mainuddin and Kirby, 2015, Midmore, 1993). The problem is more serious in developing nations since the rate of population growth is higher and economic development is unable to keep pace with it (Palaniappan, 1985). Thus, one of the ways to increase agricultural production is to increase yield per unit area (Kumar, 2012; Tamiru, 2013; Lulie *et al.*, 2016). Agriculture in the next decade will have to produce more food from less area of land through more efficient use of natural resources with minimal impact on the environment in order to meet the growing population demands (Hobbs *et al.*, 2008). Multiple cropping offers one of the best ways of increasing production per unit area by growing two or more crops of dissimilar growth habit in the same field with little intercrop competition.

Maize (*Zea mays* L.) is the most important cereal after wheat and rice with regards to cultivation area in the world (Osagie, 1998). Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socio-economic conditions (Tsedeke *et al.*, 2017). The production obtained from maize in Ethiopia in 2020 is 6,414,744.13ha with the total production of 7,774,669,728kg and productivity of 1212kg/ha (CSA, 2020). This was why Benti *et al*. (1997) explained that the annual production and productivity of maize exceeded all other crops grown in Ethiopia with the exception of teff in terms of area coverage.

Lima bean is a pulse crop commonly grown for its enlarged seeds (IBPGR, 2005) and cultivated primarily for its immature and dry seeds (Daisy, 1979 and Van der Maesen and Somaatmadja, 1989). Luis *et al.*, (2012) reported that it is important grain legume and a source of protein and other nutrients in many developing countries, contributing all essential amino acids required for human nutrition. The lima bean is grown mostly in gardens or backyards, rarely intercropped with other crops (Broughton *et al*., 2003). Even though global statistics for tropical legumes in general and lima beans in particular are lacking, Akande and Balogun (2007) indicated USA as a major producer of lima bean followed by Madagascar and Peru. In the past two decades, the total annual production was 50000-100000 tones in countries, such as Ghana, Cote d'Ivoire, Nigeria and DR Congo altogether (Baudoin, 2006).

Among the legumes, because of its growth habit and drought-tolerance ability lima bean (*Phaseolus lunatus* L) has been expected to hold the potential for intercropping with cereals like maize and sorghum (Reza, *et al.,* 2013) and also reported to increase land use efficiency (Ajala *et al.,* 2019). Lima bean is a biological N_2-fixing legume that sheds its leaves amply thus, valuable for restoring soil fertility (Ibeawuchi, 2007). Lima bean has relatively longer maturity even though some of them are perennial, it can play role in CO_2 mitigation through shunting of elevated Co_2 to nodule where it is used as energy source for symbiotic N-fixing bacteria and also through its relatively longer ever-greenness, higher CO_2 consumption in photosynthesis process and having longer period to cover soil thus leading to reduced soil erosion **(**Metwally *et al.*, 2018; Ajala *et al.,* 2019).

Cereal-legume intercropping is an important agronomic practice in which the system's efficiency is superior to the individually grown component species (Zhang *et al.,* 2021). For instance, maize-legume intercropping has multiple benefits over sole cropping and intercropping practices than other species (Renwick *et al.,* 2020). These benefits may have been achieved through symbiotic associations and complementarity interactions between species in harvesting limited resources (Brooker *et al.,* 2015). The benefits can be even greater when a legume is selected as a component crop since it can supplement some of its fixed nitrogen to other component crops (Rodriguez *et al.,* 2020). Moreover, maize and legumes may uptake nutrient elements and water from different layers since their root architecture and penetration depth are different (relatively shallow vs. deep in maize and legume, respectively). Thus, there is less competition between species (Rodriguez *et al.,* 2020).

Planting density is one of the agronomic decisions to be made by farmers while practicing the intercropping system (Nthabiseng *et al.,* 2015). Because planting density above optimum can lead to plant stress in intercropped crops and increase competition among the component crops for water, light and nutrients leading to decreased yields (Genet *et al.,* 2016, Alemayehu *et al.,* 2018). However, the trend of study on maize-climbing bean intercropping shows that higher plant density of climbing bean in the system showed for higher yield and resource use advantage (Tolera, 2005; Lulie *et al.,* 2016). In Ethiopia, intercropping of maize-climbing bean showed good compatibility by maintaining 80- 100% yield of component crops, and save up-to 73% of land as compared to sole maize (Abdisa and Girma, 1996; Habtamu *et al.,* 1996), and enhance soil fertility through biological nitrogen fixation (BNF) and leaf defoliation (low C: N which enhance maize stover decomposition rates) leading to additional yield increment (Zerihun, 2015).

Despite the advantages of cereal-legume intercropping, the prevailing production of cereal–Lima bean intercropping practice in Ethiopia is basically traditional (Leyila *et al.,* 2021) and if exercised scientifically, maize-lima bean intercropping is expected to be a growing strategy that helps to save stalking material which is currently becoming very expensive (Kenesa, 2020). Previously several studies done on maize based intercropping system reported that 44,444ha^{-1} (that with sowing spacing 75cm *30cm) was the recommended population density of maize in intercropping.

On the other hand, previously lima bean was not included in cropping system in western parts of the country. Due to the natural characteristics of this crop and its popularity in the local market, it is believed that Lima bean can play an important role in ensuring food security. However, there is no research-supported evidence (information) on the benefits of introducing lima bean crop into the cropping system due to lack of awareness among the local community and inadequate concentration by research institutions. Hypothesis of this study was therefore, system productivity of maize-lima bean intercropping can be improved through optimized population density of lima bean in maize stands. Hence, the present study was undertaken generally to determine the productivity of maize-lima bean intercropping system as an expense of population density of lima bean at Jimma, south western Ethiopia. Therefore, the specific objectives:

1. To determine the optimum density of lima bean in maize-Lima bean intercropping for better performance of component crops

2. To evaluate land productivity and yield advantage of maize-lima bean intercropping system at the study area.

2. LITERATURE REVIEW

2.1. Maize Production and its Importance in Ethiopia

Ethiopia is fourth ranked maize producers in Africa following South Africa, Nigeria and Egypt. The crop is widely cultivated at altitudes ranging from 1500–2200 meters above sea level of throughout different parts of the country. Regional states including Oromia, Amhara and SNNP contribute above 90% of the total annual production. Oromia region alone contributes to 67% of the country's maize production. West Gojam, East Showa, Jimma, East Wollega and West Wollega zones are major producing areas and together contribute to 60% of total production (Ethiopia Commodity Exchange Authority, 2019). The mid altitude, sub-humid agro-ecology is the most important maize producing environment in Ethiopia (Birhane and Bantayehu, 1989; Kebede *et al*., 1993). Agriculture continues to be the dominant sector in Ethiopia's economy, with cereals playing a central role. Grain production and marketing are particularly important: studies show that cereals account for 65 percent of the agricultural value added, equivalent to about 30 percent of the national GDP (IFPRI, 2010). Out of the total grain crop area, 78.17% (9,601,035.26 hectares) was under cereals, from which maize covers 17.49% (about 2,313, 0194.36 hectares) of the grain crop area (CSA, 2019).

Maize continues to be a significant contributor to the economic and social development of Ethiopia. Maize is increasingly used for human consumption and accounts for 70% of the food consumed in sub-Saharan Africa (FAO, 2007). As the crop with the largest smallholder coverage at 8 million holders, maize is critical to smallholder livelihoods in Ethiopia. In addition, maize is the staple crop with the greatest production (IFPRI, 2010). In addition, because of its productivity and wide adaptation, maize remains an important source of food with great potential to improve the livelihoods of most poor famers in developing countries (FAO, 2011). Maize is instrumental for the food security of Ethiopian households, and is the lowest cost caloric source, which is significant given that cereals dominate household diets in Ethiopia. An average Ethiopian consumes a total of 1,858 kilocalories daily of which four major cereals (maize, teff, wheat, and sorghum) account for more than 60 percent, with maize and wheat representing 20 percent each (IFPRI, 2010).

2.2. Lima Bean Production and its Importance in Ethiopia

Lima bean sometimes called butter bean is one of an important grain legume grown in South Western Ethiopia. It is cultivated in the home gardens or intercropped with cereals in the field. Lima bean seeds are different from each other in their size, shape, color and appearance of eye (EBI, 2012) and having high protein (210-260 g/kg) and high carbohydrate contents (550-640 g/kg), low fat (10-23 g/kg) and fiber levels (32-68 g/kg), high levels of minerals such as K, Zn, Ca and Fe, and low levels of Na and P (Oshadi, 1993). Lima bean is mainly produced for consumption as only 35% of the grain produced is sold (Saka *et al.,* 2004). The dried seeds are eaten after getting them boiled with other cereals and pulses, a dish locally known as "nifro". In the same way, Lima bean is cultivated in Nigeria mainly for the dry seeds like other grain legumes. It is an important source of vegetable protein and a N_2-fixing legume that sheds its leaves copiously thus, valuable for restoring soil fertility (Ibeawuchi, 2007).

In Ethiopia it is mainly found in the Chercher area of Hararge, in the lower regions of Shoa and Arsi, and to a lesser extent in the south-west of the country. Dried seeds have been observed at the markets of Shoa (lower regions), Wollega (lower regions), Kefa, Gamu Gofa (e.g. Konso area), Sidamo, Arsi (lower regions) and Hararge. There is shortage of reported production and productivity of lima bean crop (Purseglove 1968, Kenesa, 2020).

2.3. Maize Plant Origin and Requirements

There is some disagreement on the origin of maize, though it is generally accepted that its Centre of origin is located in Mesoamerica, primarily. Its domestication, probably from a wild teosinte form (*Euchlaena Mexicana*), is believed to have started some 6,000 to 7,500 years ago in the Mexican highlands (McCann, 2001). Maize is a one of the grass family *Poaceae (Gramineae),* a classification is similarly with wheat, rice, oats, sorghum, barley, and sugarcane. It is further organized in the genus *Zea*, a group of annual and perennial grasses native to Mexico and Central America (Edward *et al*., 2005).

Maize reached in Africa after 1500 as part of the huge global ecological and demographic transformation that historian Alfred Crosby called the "Columbian Exchange." The importation of the maize seeds to various parts of Africa generally went unremarked, though it certainly was not unremarkable. The first reference to maize's introduction to Africa may be that of an anonymous Portuguese pilot in 1540, who described its already well-established cultivation on the Cape Verde Islands (McCann, 2001). Maize is first introduced in Ethiopia in 16^{th} century (Yoseph *et al*., 2006).

Maize is a 2-3 m high grass with a solid single stem, 3-4 cm in diameter, with clearly defined nodes and 15 to 20 internodes. The leaves arise from the nodes, alternately on opposite sides on the stalk. It is a monoecious grass with male and female flowers borne in separate inflorescences on the same plant. The tassel male inflorescence is a terminal panicle, up to 40 cm long, which stretches out from the enclosing leaves at the top of the stalk. The male or staminate flowers are present within spikelet on the branches. The maize kernel consists of the embryo (10-13% of the grain), endosperm and pericarp and may differ in color, structure and chemical composition (McCann, 2001).

Maize is the primary produced for its staple food in Ethiopia, averaging slightly more than 20% of daily caloric intake. Currently, it is the second most important crop, exceeded only by teff (*Era-grostisteff)* in terms of production area. However, it exceeds all other cereals in terms of annual production and yield per hectare. The Ethiopian Commodity Exchange reports that three-quarters of maize produced is used for household consumption, only about ten percent is marketed and the remainder is used for seed, in-kind payments for labor, and animal feed (Schneider and Anderson, 2010). It is one of the cereals that provide most of the calorie requirements in the traditional Ethiopian diet (Mulatu *et al*., 1992). Apart from these uses maize leaves are feed to animals, while dry stalks are used as fuel and for the construction of fences and huts.

2.4. Lima Bean Plant Origin and Morphological Requirements

According to Smýkal *et al.* (2015), lima bean and all the species in the genus *Phaseolus* are originated in the tropical America. Mackie (1943) reported that Lima bean is originated in Guatemala. However, later on several scholars have studied and made it clear that it has more than one center of origin: the Andes (Peru) and Mesoamerica (Debouck *et al*., 1989).

It is believed that Lima bean has been grown for more than 10,000 years in the New World (Kaplan, 1965). Concerning the areas of domestication, Kaplan (1965), put forward the assumption that particularly big Lima types may have been domesticated at the warm humid regions, East of the Andean highlands. Erickson (1982) considered the central part of Amazon Basin in Brazil as the area where extremely large seeded cultivars were found being cultivated. Further, Andueza-Noh *et al.* (2015) concluded that the landraces domesticated in the Central-Western Mexico are not genetically homogenous as it would be expected in a scenario of a single domestication, and hence, this leads to accepting that lima beans were domesticated more than two times. In post-Columbian times Lima beans widely spread, particularly in the tropics. Carib-type beans were taken by the Spanish galleons across the Pacific to the Philippines and from there to Asia. The slave trade took them from Brazil to Africa. All modern large lima beans trace back to Peru and were taken at an early date to Madagascar (Purseglove, 1968).

In Ethiopia the lima bean is especially found in the south-western part of the country, but it is also cultivated in Hararge. The crop is climbing, slightly white and brownish pubescent perennial (bush forms not seen in Ethiopia). Sometimes globular nodules present (Erickson, 1982). Even though lima bean has many importance, the crop is one of the neglected and underutilized grain legumes (MNUGLs) which is primarily characterized by inherent features and capabilities to withstand the effects of abiotic stress and climate change as well as boosting food and protein security (Popoola *et. al.*, 2019).

2.5. Cropping System

Cropping system is the philosophies and practices of cropping and their interaction with farm resources, technology, aerial and edaphic environment to suit the regional or global needs and production strategy (Pal *et al.*, 1985). Recently, the research on cropping system has attracted attentions worldwide. Temporal and spatial intensification of crops constitutes the basic ingredients of national food production strategy that to create diverse income source and labor use distribution. Maize/ legume, particularly bean are the dominant cropping systems in most parts of Africa (Francis *et al*., 1982).

In Ethiopia, even though mono cropping of maize is the dominant feature, mixed cropping of maize with pulses, oil crops, cereals and even trees are common cropping practices in most part of maize growing area (McCann, 2001). The economic return or monetary gain per unit area and time is one of the major considerations for adoptions of a certain cropping system and yield is the foremost agronomic parameter to compare the importance of component crop in any type of cropping system. Soil fertility, temperature, length of rainy season and pressure on the land influence the type of cropping systems used by smallholders (Woolley *et al*., 1991). In general, crop intensification, crop diversification and cultivar options are the three inseparable approaches used in designing alternative cropping system and is considered as a building block of a new system (Yadav *et al.*, 1998).

2.5.1. Intercropping

Different authors defined intercropping differently, with similar basic idea. Intercropping is a type of multiple cropping in which two or more crops are grown simultaneously in the same field at the same time and space (Moradi *et al.,* 2014). Plants of different species can be closely arranged to optimize positive plant growth interactions (Belel *et al.,* 2014). Common characteristics of different forms of intercropping have the effect on intensifying crop production and exploiting more efficiently environments with limiting or potentially limiting resources (Trenbath, 1982). Andrews and Kassam (1993), further divide intercropping in to four: mixed intercropping, row intercropping; strip intercropping (growing component crops simultaneously in different strips to permit the independent cultivation of each crop); and relay intercropping.

Crop combinations in intercropping should be opposing with crop morphology and growth durations. Thus, combination of crops for intercropping should be primarily determined by the length of the growing season, interspecific supporting habit between component crops and the adaptation of crops to particular environment (Ofori and Stern, 1987).

2.5.2. Maize and Legume Intercropping

One of the main challenges in Ethiopia, particularly where maize is the main stable and major producing crop, is continuous mono cropping with residue removal through burning and/or used for other purposes (Zerihun *et al*., 2014). Maize-legume intercrops yielded more and were associated with less risk than the maize legume rotations (Kamanga *et al*., 2010) which also gives higher net return (Patra *et al*., 2000). In case intercropping was to be practiced, there would be a higher coverage of the soil by the second crop and so, it forms green or living mulch, at the same time decrease the bare soil surface evaporation. This would then also increase the water use efficiency of the combined crop (Walker and Ogindo, 2003).

A modification of growth habit from bush to climbing beans in maize/bean intercrop system changes both temporal and spatial arrangements of the cropping system (Woolley and Davis, 1991). However, beans have been reported to be less competitive than maize for light. Maize crop shades the associated bean crop thus, depressing yield due to the decreased in photosynthetic in plant, which is reflected in reduced number of pods per plant and seeds per pod (Davis and Garcia, 1983). Maize was reported to depress bush bean yields by 7 to 32%

(Woolley and Smith, 1992), whereas beans caused 15 to 30% reduction in maize yield (Davis and Garcia, 1987).

Reduction in bean yields may be minimized by manipulating plant density and relative planting dates (Niringiye *et al*., 2005). Intercropping has been avoided because of the complications of planting and harvesting. However, intercropping usually benefits from increased light interception, root contact with more soil, increased microbial activity and can act as a constraining to pests and weeds (Avcioglu *et al*., 2003). There is also evidence that suggests intercropping may benefit a non-legume which needs nitrogen if the other crop is a legume, as legumes will fix nitrogen (Avcioglu *et al*., 2003).

2.6. Role of Intercropping for Better Production and Risk Avoidance

Situating more land to agricultural production (can go only to a limited extent) and increasing productivity per unit of land (has more possibilities that require the generation) are the two ways of increasing crop production and application of technologies especially suited to the environment and situation of the farmer (Habtamu *et al.*, 1996). In most multiple cropping systems developed by smallholders, productivity in terms of harvestable products per unit area is higher (yield advantages can range from 20% to 60%) than under sole cropping with the same level of management (Steiner, 1984).

Among multiple objectives, the main advantage of intercropping systems is efficient and complete use of growth resources such as solar energy, soil nutrients and water (Siva and M., 1993). Some of the suggested reasons for the popularity of intercropping in the tropics and subtropics are: efficient use of growth resources like water, nutrients and light (Natarajan and Willey, 1980); highest yield and greater land use efficiency (Ofori and Stern, 1987); inexpensive weed control (Enyi, 1973); minimization and avoidance of agricultural risks (Willem, 1990; Rao and Willey, 1980); improvements of soil fertility (Bandyopadhay and De, 1986); minimization of peak of labor and demand (Okigbo and Greenland, 1976).

Moreover, socio-economic reasons include the amount of inputs and out puts and their contribution to the stabilization of household food supply (Beets, 1982). Thus, there is recognition of the great potential of intercropping to increase agricultural productivity and conserve natural resource. Intercropping presents a large level of risk reduction for the smallholder. If one crop is entirely lost to pest or drought damage, the farmer may still harvest the other crop in the field. Given the unpredictable rainy season and the different water requirements of each crop, planting many varieties of the same crop in an intercropped field gives the farmer a better chance that some crops will survive (Carlson, 2008).

2.7. Resource Use in Intercropping System

The main advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture (Mucheru *et al*., 2010). Yield advantage occurs because growth resources such as light, water, and nutrients are more completely absorbed and converted to crop biomass by the intercrop over time and space as a result of differences in competitive ability for growth resources between the component crops, due to variation of the mixed crops in characteristics such growth habit. Intercropping has greater radiation capture potential and utilization as compared with sole cropping, because of the effect of combination of differing spatio-temporal use of radiation among component crops (Willey, 1990; Tsubo *et al*., 2001).

Maximizing intercropping advantages is therefore a matter of maximizing the degree of complementarity between the components and minimizing inter-crop competition (Rezende and Ramalho, 1994). On this basis, intercropping advantages are more likely to occur where the component crops are very different. Probably the main way that complementarity can occur is when the growth patterns of the component crop differ in time so that the crops make their major demands on resources at different times (Trenbath, 1974).

2.8. Effects of Intercropping on Maize and legume crops

Even though there is no research-based reports on effects of Maize-Lima bean intercropping, studies on maize-bean has showed the more yield and economic advantages. For example, Makgoga (2013) showed that when maize was intercropped with dry bean, the maize obtained highest number of cobs per plant. The highest number of cobs per plant was obtained in maize/dry bean intercropping followed by sole maize. Plant height and 100 seeds mass in maize/dry bean intercropping were higher, 2.0 m and 30.8 g, respectively, followed by sole maize 1.9 m and 30.4 g. Maize/dry bean intercropping and sole maize produced high grain yield of 2156.3 kg/ha and 2093.7 kg/ha, respectively (Makgoga, 2013).

2.9. Plant Density in Intercropping System

The intercropping population and the relative proportion of individual combined crops are very important in determining yields and production efficiencies of cereal-legume mixture (Zardari *et al.*, 2013). Plant population describes the number of plants per unit area, which regulate the size of the area available to the specific plant (Willey, 1979a). Seeding ratios and competition capability within mixtures may affect the growth of the species used in intercropping systems in rain-fed areas (Carr *et al*., 2004; Agegnehu *et al*., 2006; Banik *et al*., 2006; Dhima *et al*., 2007). When the components are present in approximately equal numbers, productivity and efficiency appears to be determined by the more aggressive crop, usually the cereal (Zardari *et al.*, 2013).

Plant density determines the degree of competition among plants (Ipsilandis and Vafias, 2005; Kgasago *et al*., 2006). Tsubo *et al*. (2003) have presented the yield and growth advantages of maize-bean intercropping in the study region, which is in an agreement with previous studies in the other African regions. Concerning resource use, both RUE (radiation use efficiency) and WUE (water use efficiency) of maize-bean intercropping are equivalent to or higher than maize sole cropping, and they are higher in RUE and WUE than bean sole cropping. From those results, it follows that when farmers plan on cultivating both crops, planting maize associated with beans is more advantages than sole cropping. Plant density affects crop productivity and resource use of the intercropping (Tsubo *et al*., 2003).

Ofori and Stem (1987) proposed that the growth and yield of the legume component is reduced markedly when intercropped with high densities of the cereal component. In a maize/bean intercrop system, increasing maize density three-fold, from 18, 000 to 55, 000 plants/ha, reduced bean leaf area by 24% and seed yield by 70% (Gardiner and Craker, 1981). Spatial arrangement of component crops is one of the most important agronomic factors that determine whether an intercrop system will be advantageous or not with regard to yield gains (Natarajan and Shumba, 1980).

2.10. System Productivity and Profitability of Intercropping Systems

According to Layek *et al.* (2014), several indices such as land equivalent ratio (LER), crop equivalent yield, and monetary advantage index (MAI) have been suggested to describe productivity of intercropping compared to monocropping system. Land equivalent ration (LER) is the most commonly used index to compare type of cropping. Its inherent use is that different crops whatever their type or levels of yield, are put on a relative and directly comparable basis. To avoid bias because of differences in yield proportions, it can be calculated based on monetary values (Willey, 1979). Crop equivalent yield is another expression for evaluating the efficiency of intercropping system (Yogesh *et al.,* 2014). In maize-legume intercropping system, total yields are converted in the form of base crop equivalent yield by considering the intercrop yield and market price of base crop and associated intercrops. If the base crop equivalent yield is obtained higher in intercropping combinations than base crop yield, then intercropping is considered advantageous.

Additionally, the most important part of recommending a cropping pattern is the cost benefit ratio more specifically totals profit, because farmers are mostly interested in the monetary value of return. The yield of all the crops in different intercropping systems and also in sole cropping system and their economic return in terms of monetary value was evaluated to find out whether maize yield and additional legume yield were profitable or not. This was calculated with monetary advantage index (MAI) which indicates more profitability of the cropping system with the higher the index value (Mahapatra, 2011).

3. MATERIAL AND METHODS

3.1. Description of study areas

The experiment was conducted at Seka Chokorsa district (Seka-site) and Nadhi Gibe district (Dimtu-site) of Jimma zone of the Oromia Regional National State, South Western Ethiopia, during 2022 main cropping season. Seka experimental site was located at 368 km southwest far from Addis Ababa. This site has latitude and longitude of $7^0$40N and $36^0$50 E respectively, and also its average elevation 1835m above sea level. The soil type of Seka was Eutric Nitisol (Reddish brown), acidic in reaction (Table 2). Mean annual rain fall of the study area was 1714mm with maximum and minimum temperatures of 26^oc and 12.34^oC respectively (JARC, 2021).

Dimtu was located at 7°15’16” latitude and 42°17’55” longitude at an elevation of 1790m above sea level. The average annual rainfall is 1300-1704mm from (the National Meteorology Agency of Ethiopia). The average minimum and maximum temperature were 10.0 and 29.0°C, respectively. The soil of the study area was Silty clay in texture, acidic in reaction, medium in total N, and low in available P and low in OC (Table 2). Both study area is characterized by cereal based cropping system. The major crops are maize, teff and sorghum whereby mono-cropping of these cereals dominates in the area.

3.2. Experimental materials

Maize variety of BH-661 and seed of Lima bean of JULB-012 accessions maintained at JUCAVM, which has indeterminate growth habit, was used as experimental materials in this study.

3.3. Treatments and experimental design

The experiment included of five treatments having different planting proportion of Lima bean (LB) intercropped with Maize (M). The five treatments were adjusted as: Sole M (T_1), Sole LB (T_2), LB spaced at 35cm and intercropped with M (T_3), LB spaced at 50cm and intercropped with M (T_4), and LB spaced at 65cm and intercropped with M (T_5) details of each treatment is described in Table 1**.** The experiment was laid out in RCBD with four (4) replications and five (5) treatments. Distance between plot and block was 1m and 1.5m respectively. Each plot area was $22.5m^2$ (4.5m x 5m).

Table 1. Treatments with their descriptions and planting distribution in each plot

Treatments	Maize				Lima bean				Total plant $Plot^{-1}$	Total Plant ha^{-1}	Total Plant ha^{-1}	
	Spacing (cm)	Numb. Rows $plot^{-1}$	Numb. Plants Row^{-1}	Numb. Plant $Plot^{-1}$	Spacing (cm)	Numb. Rows $Plot^{-1}$	Numb. Plants Row^{-1}	Numb. Plant $Plot^{-1}$	M + LB	Maize	Lima bean	M + LB
T_1	75 x 25	6	20	120	-	-	-	-	120	53,333	0	53,333
T_2	-	-	-	-	75 x 20	6	25	150	150	0	66,666	66,666
T_3	75 x 30	6	16	96	75 x 35	6	14	84	180	44,444	38,095	82,539
T_4	75 x 30	6	16	96	75 x 50	6	10	60	156	44,444	26,666	71,110
T_5	75 x 30	6	16	96	75 x 65	6	7	42	138	44,444	20,512	64,956

T1, T2, T3, T4 and T5 were symbolized as: Sole M, Sole LB; LB spaced at 35cm, 50cm and 65cm respectively.

3.4. Experimental procedure and crop management

Once the site was selected, then land was cleared manually from all vegetation and residues to ensure good germination and reduced weed and pest infestation. Soil cultivation was carried out by oxen. The same plot size (i.e. 4.5m x 5m = 22.5m^2) was prepared in such a way that able to hold six rows that used for both crops. Planting was carried out when the soil is moist using sowing depth of 5 and 7cm for maize and Lima bean respectively. Uniform row spacing of 75cm was used for M and LB in all treatments. Sole and intercropped M was planted at plant spacing of 25 and 30 cm respectively, whereas sole LB was planted with 20cm planting space. Variation in LB plant density was obtained by varying within row spacing (i.e. 35cm, 50cm and 65cm).

Sowing of Lima bean was delayed by 15 days from maize to build maize capacity to support Lima bean plants. Two seeds of maize and LB per hill were sown between the maize stands at intra-row spacing of 35, 50 and 65cm, later will thinned to one plant per stand at14 days after sowing (DAS). For LB spaced at 35cm and intercropped with M (T_3), LB was sown between maize, with 35cm spacing. The same sowing procedures were used for T_4 and T_5 with assigned spacing for each treatment which is 50 and 65cm respectively. Lima beans in intercrop were planted 15 days after emergence (DAE) of maize to ensure that maize plants would be ready in time for supporting lima bean.

All field management practices carried out for both crops as required. NPS (200kg/ha) and Urea (100kg/ha) was used as source of fertilizer at planting time for both crops. Weeding was done manually by week interval whereas insect and disease monitoring was done regularly and controlled by previously advised type and amount. Harvesting operation of Lima bean was done at physiological maturity i.e. when the pods start yellowing before complete brittle, since harvesting of maize was done only by removing cobs because maize stalk was helps for supporting Lima bean.

3.5. Soil sampling and analysis

Soil samples were collected from each plot to 0-20cm soil depth before planting and after harvesting using soil auger and bulked into a composite sample for laboratory analysis for the physical and chemical properties of the soil. Uniform slices and volumes of soils were obtained in each sub-sample by vertical insertion of an auger. The samples were air-dried, ground to pass through a 2mm sieve (Dume *et al.,* 2015), except for analysis of organic carbon and nitrogen, where the samples were passed through 0.5mm sieve. Working samples were obtained from submitted samples and was analyzed for selected physical and chemical properties such as texture, soil pH, organic carbon, total N and available phosphorus and potassium using standard laboratory procedures.

Total N in the soil was determined by the Kjeldahl method (Dewis and Freitas, 1975). Organic carbon content of the soil was determined by reduction of potassium dichromate by organic carbon compound and determined by reduction of potassium dichromate by oxidation reduction titration with ferrous ammonium sulfate (Walkley and Black, 1934). Particle size distribution (texture) was determined by hydrometer method (differential settling within a water column) using particles less than 2mm diameter (FAO, 2008). This procedure measures percentage of sand (0.05 - 2.0 mm), silt (0.002 - 0.05 mm) and clay (<0.002 mm) fractions in soils.

Available P was determined following the method of Olsen and Dean (1965). The pH of the soil was measured in 1:2.5 (weight/volume) soil samples to $CaCl_2$ solution ratio using a glass electrode attached to digital pH meter (Page *et al.*, 1982). All the selected chemical properties of the soil were analyzed at Horticoop Ethiopia soil and plant analysis laboratory at Bishoftu.

Soil Physicochemical properties before Planting:

The analyzed physic-chemical properties of the soil before planting showed that the soil was clay loam in texture based on soil textural classification triangle with acidic pH, 5.65 at Seka (Table 2) indicating that these properties are favorable for both maize and Lima bean production. Maize can grow nearly in arable areas of Ethiopia but deep and well drained soils with pH of 5.0-7.0 are better suited (Tolessa *et al*., 2001). The lima bean crop is also not sensitive to such soil type and a pH greater than 5.3 is suitable for legume crop growth (Wortman, 2006). Additionally, it was also reported that loam or silt loam surface soil and brown silt clay loam rich in organic content are the ideal soil types for cultivation of bean varieties (FAO, 2013).

The organic carbon content of the experimental soil (2.25% at Seka and 1.5% at Dimtu) was low as rated by Landon (1991). The total nitrogen content (0.19% at Seka and 0.2% at Dimtu) of the experimental soil was medium (Table 2) in accordance with the ratings of Tekalign (1991), indicating that the nutrient was not a limiting factor for crop growth. The available P of the experimental sites was 4.43 and 3.76mg kg^{-1} at Seka and Dimtu respectively, (Table 2) could be considered as low accordance with Landon (1991). This indicated that P is limiting nutrient for optimum crop growth and yield in the experimental site. In general, the properties of the experimental soil and the weather conditions at the sites were favorable for growth of both crops.

Table 2 Selected soil physical and chemical properties of Seka and Dimtu experimental site before planting in 2022/23cropping season

Experimental Sites	**Physical properties**				**Chemical properties**			
	Distribution of Particle size (%)			Texture class	pH	Total N (%)	Organic C (%)	Available P (mg kg^{-1})
	Clay	Silt	Sand					
Seka	40	26	34	Clay loam	5.65	0.19	2.25	4.43
Dimtu	77.3	19.7	3.0	Clay loam	5.3	0.20	1.50	3.76

3.6. Data Collection and Measurements

All data were recorded from the central rows of each plot on per plant basis. For those data to be recorded per plant basis (plant height, number of pods, seeds per pod, number of cobs, seeds per cob, number of rows/cobs, weight of 100 seeds (g) and grain yield (kg/ha) sixteen plants were randomly selected and ear tagged from each plot and the average was taken. Methods of measurement for each parameter and crop-specific data were described below.

3.6.1. Phenological parameters

Maize: Days to tasseling was taken as the number of days required from emergence to tassel production by 50% of maize plants in the plots. Days to silking was recorded as the number of days required from emergence to silking by 50% of maize plants in the plots. Days to physiological maturity was recorded as the number of days from emergence to the formation of a black layer in the kernel at the point of attachment of the kernel with the cob by 90% of maize plants in the plots.

Lima bean: Days to flowering and physiological maturity were not determined as the crop’s growth nature has continuous until the whole crops become mature.

3.6.2. Plant growth parameters

Maize plant height: was measured as the height from the soil surface to the base of the tassel of sixteen randomly taken plants from the net plot area using measuring stick at physiological maturity and the average was taken for analysis.

Cob length: was measured as the length of the ear following removing of the sheath after harvest.

Leaf area: at 50% silking, leaf area was determined from sixteen randomly sampled plants per plot and the leaves from each plant categorized into small, medium and large leaves. Then it was calculated by multiplying leaf length and maximum breadth adjusted by a correction factor of 0.733 (i.e. 0.73 x leaf length x maximum breadth) as described by McKee (1964).

3.6.3. Yield and components yield

To collect maize yield components and yield the stand count was counted at physiological maturity before harvesting. Number of cobs per plant, kernels per row, and rows per cob, and cob length, hundred seed weight (g) was determined by putting 100 kernels into three replications and weighting them separately using sensitive balance and finally their averaged weight was taken and adjusted to 12.5% moisture content.

Seed yield per plot: was measured using electronic (steelyard) balance and then adjusted to 12.5% seed moisture content using a digital moisture tester (model M-3G) and was converted to hectare basis. Adjusted yield was calculated using Hellevang (1995) formula:

$$Adjusted\ yield = \frac{(100 - actual\ moisture)}{(100 - standard\ moisture)} * Obtained\ yield$$

Above Ground Biomass: was measured from the net plot area including leaves, stems and seeds which were harvested at physiological maturity just before cob removal and weighed after seven days of sun drying.

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

$$\mathrm{HI} = \frac{\mathrm{GY}\left(\frac{\mathrm{ton}}{\mathrm{ha}}\right)}{AGB\left(\frac{ton}{ha}\right)} * 100$$

Where, HI= harvest index; GY=Grain yield (at 12.5% moisture base) and AGB=above ground biomass (Stover +grain yield).

Lima bean: For Lima bean yield and yield components data collection**,** crops' stand count per plot was counted at physiological maturity before harvesting and then already reached data were collected and the average was used.

Lima bean pod length: was measured as the length of the pod from pod attachment to stem to tip of each sampled pods after harvest.

Number Pods per plant: were counted from all lima bean plants from each plot at physiological maturity round by round and recorded as 1^{st} to 4^{th} round of harvesting and the average was recorded for each plot.

Number of seeds per pod: was recorded from 100 randomly sub sampled pods from each plot and the average was taken in each harvesting round and the average was recorded.

Hundred seed weight: was determined from 100 seeds randomly taken from each plot and weighed using sensitive balance and then adjusted to 10% seed moisture content. Seed yield per plot was measured using electronic balance (steelyard) and then adjusted to 10% seed moisture content using digital moisture tester and converted to hectare basis. Adjusted yield was calculated by using the above formula (Hellevang, 1995).

3.7. Analysis of Maize-Lima bean intercropping System Productivity

According to Layek *et al.* (2018), several indices such as land equivalent ratio (LER) and crop equivalent yield have been suggested to describe economic advantage of intercropping compared to monocropping, and the two indices were used in this study to evaluate maize-lima bean intercropping system productivity.

Land equivalent ratio (LER)

Land equivalent ratio is defined as "an index of intercropping advantage and a reflection of the degree of interspecific competition or facilitation in an intercropping system" (Zhang *et al.,* 2011). Another definition of LER is the "relative land area required as a sole crop to produce the same yields as intercropping" (Mead and Willey, 1980). Land equivalent ratio measures the levels of intercrop interference on the cropping system. Then, a LER higher than 1.0 indicates an intercropping advantage or positive interspecific interference that exist in the mixture, and LER less than 1.0 reflects mutual antagonism or competition in the intercropping system (Zhang *et al.*, 2011). The LER value equal to 1.00 indicates no gain or no loss and less than 1.00 indicates yield loss in intercropping system (Papendick, 1989). The LER values will be computed using the following formula described by Willey *et al.* (1983).

LER= Y_{ab}/Y_{aa}+ $Y_{ba}/Y_{bb;}$ Where, Yab and Yba are yield of maize and haricot bean in an intercropping system respectively and Y_{aa} and Y_{bb} are yield of maize and haricot bean in pure stand of each crop respectively.

Crop equivalent yield

Crop equivalent yield is another expression for evaluating the efficiency of intercropping system (Yogesh *et al.*, 2014). In maize-legume intercropping system, total yields are converted in the form of base crop equivalent yield by considering the intercrop yield and market price of base crop and associated intercrops. If the base crop equivalent yield is obtained higher in intercropping combinations than base crop yield, then intercropping is considered advantageous. Maize and Lima bean equivalent yield (MEY) were calculated to assess their mixed system productivity. Maize equivalent yield is the sum of maize yield in the intercrop system and the converted legume yield, and compared with sole crop maize yield (Jan *et al.*, 2016), and it is expressed in kg ha^{-1}. Yield of individual crop in the intercropping will be converted into equivalent yield on the basis of the prevailing market price of each crop (Prasad and Srivastava, 1991). The same procedure is followed to calculate lima bean equivalent yield.

MEY and LbEY are calculated by:

$$\boldsymbol{MEY = YiM + \left(\frac{YiLb \, * \, PLb}{PM}\right), \qquad and}$$

$$\boldsymbol{LbEY = YiLb + ((YiM \, * \, PM)/PLb)}$$

Where, MEY and LbEY are Maize and lima bean equivalent yield respectively, YiM= Yield of intercrop maize, PLb= Price of Lima bean, PM= Price of maize and YiLb= Yield of intercrop lima bean.

3.8. Statistical analysis

Before data analysis, data were checked for meeting the basic ANOVA assumptions such as normality using SAS software. The data collected were checked for normality using Shapiro Wilk and showed data were normally distributed. Also, homogeneity tests were made for error variances for the parameters across the sites using the F_{max} test before proceeding to the analysis of variance.

$$F_{max} = \frac{\text{Larger mean square error}}{\text{Amaller mean square error}}$$

As the $F_{max} \geq 3.00$, the parameters were considered heterogonous so that separated analysis of variance (ANOVA) for the two site’s data was done using SAS (statistical analysis system) version 9.3 program (SAS Institute, 2012). Difference between treatments means were compared using least significance difference (LSD) test at 5% level of significant. Additionally, a Pearson correlation analysis was performed to determine relationship among yield and yield components of both maize and lima bean.

4. RESULTS AND DISCUSSION

4.1. Phenology and Growth Response of Maize

4.1.1. Date of fifty percent tasseling, silking and ninety physiological maturity

The analysis of variance for Seka site showed that days to 50% tasseling, 50% silking and 90% maturity were not significantly ($P>0.05$) influenced by population density of Lima bean when intercropped with maize (Table 3 and Appendix Table 1). It might be from the environmental factors that did not cause influence on phenology of maize; because the experimental location of the plant was the same for all and it did not cause variation on maize phenology (Table 3). Similar to this finding, Yesuf (2003) reported that days to 50% emergence and maturity of maize/common bean and sorghum/common bean intercropping are not affected by component planting density.

However, only DPM was showed significance ($p<0.05$) at Dimtu site that might be because of early stopping of rain at this experimental site (Table 3 and Appendix 1 and 2). Relatively, sole cropped maize took longer days to 50% tasseling and silking than intercropped maize. Similarly, Abraha (2013) mentioned that maize mono crop has a growth period of 120 days and this was not significantly different from maize intercropped with cowpea cultivars. Also Jibril *et al.*, (2015)) reported that maize mono crop has a longer growth period and this was not significantly different from maize intercropped.

Table 3 Growth and Phenological parameters of Maize under maize-Lima bean intercropping at Seka and Dimtu sites

Locations	**Treatments**	Phenological and Growth parameters of maize				
		Days to 50% tasseling	Days to 50% silking	Days to 90% physiol. maturity	Leaf Area (cm^2)	Plant height (cm)
Seka	Sole maize	120.3	127.75	157.5	554.55[a]	262.5
	Sole Lima bean	-	-	-	-	-
	LB spaced at 35cm and intercropped with M	117.3	125.25	153.25	526.95[ab]	277.1
	LB spaced at 50cm and intercropped with M	118.5	126.25	154.25	515.75[b]	266.3
	LB spaced at 65cm and intercropped with M	119.8	127.5	155.25	510.30[b]	264.15
LSD(5%)		NS	NS	NS	NS	NS
Dimtu	Sole maize	112	121.0	151[a]	523.43[a]	284.0
	Sole Lima bean	-	-	-	-	-
	LB spaced at 35cm and intercropped with M	111.7	119.3	148[b]	467.03[b]	298.0
	LB spaced at 50cm and intercropped with M	110	119.7	149.3[b]	453.60[b]	293.0
	LB spaced at 65cm and intercropped with M	112	120.3	147.7[b]	420.47[c]	290.0
LSD (5%)		NS	NS	**2.4**	NS	NS

Means followed by the same letter within a column are not significantly different from each other at 5 % level of significant.

4.1.2. Maize Leaf area

The total leaf area of maize was significantly ($P<0.05$) increased by the planting density of Lima bean in intercropping with maize at both Seka and Dimtu site (Table 3 and Appendix Table 1 and 2). The overall highest (554.55 and 523.43cm^2) leaf areas of maize were recorded from sole maize at Seka and Dimtu respectively (Table 3). Among intercropped systems, 526.95 and 467.03cm^2 were the widest maize leaf area recorded when maize inter cropped with 38,095ha^{-1} LB spaced at 35cm and intercropped with M at Seka and Dimtu respectively (Table 3). Whereas, the narrowest leaf area (510.3 and 420.47cm^2) were recorded from the lowest population density of Lima bean (20,512ha^{-1}) at both Seka and Dimtu respectively (Table 3). As all the reduced maize leaf area recorded when intercropped with lima bean could be due to the greater lima bean plant height and reduce leaf growth of maize from low light interception during the latter growth stages.

As indicated in the result the wider leaf area was observed in the higher population density that might be resulted from interspecific competition between plants for light in intercropped plots, this might be the time at which lima bean growth and cover the maize was the critical period at which light must be harvested by crops, thus greater assimilate must be supplied by the leaf in order to increase yield. Similarly, Yesuf (2003) reported that the leaf area of sorghum was significantly reduced due to the effect of population density. Also, in maize-bean intercropping it was reported that intercropping significantly affected leaf area of maize at higher population of component crops (Demesew, 2002; Tolera (2005). Likewise, Jibril *et al.,* (2015) stated that population density of common bean have been showed significant effect on the leaf area of maize.

4.1.4. Plant height

The effects of population densities of Lima bean intercropped with maize was found non-significant ($P>0.05$) on mean plant height of maize at both site (Table 3 and Appendix 1 and 2). Even though there was no previously reported evidence maize-Lima bean intercropping, a lot of reports on maize-climbing bean intercropping agree with the present study. For example, Demesew (2002) reported that common bean planting density had no significant effect on plant height of sorghum and maize under intercropping. Jibril *et al.,* (2015); Lulie *et al*., (2016) reported that maize plant height was not significantly affected by the associated haricot bean densities and varieties. Thobatsi (2009); Makgoga (2013) also stated that intercropping of maize with grain legumes had no significant differences in maize plant height.

4.2. Yield and Yield Components of maize

4.2.1. Number of cobs per plant:

The analysis of variance indicated that the population density of lima bean as intercropped with maize had highly significant ($P<0.001$) effect on number of cobs per plant of maize at both site (Table 4 and Appendix Table 3 and 4). The highest number of per plant (1.53) was recorded from sole maize (1.28 and 1.23) followed by when maize intercropped with 20,512 and 26,666 ha^{-1} Lima bean population density respectively at Seka site, whereas the lowest number of maize cob per plant (1.03) was recorded when 38,095 ha^{-1} of lima bean density was intercropped with maize (Table 4). Similarly, among intercropped plots, 1.3 and 1.1 was the higher and lower cob number per plant was recorded when the lowest and highest population of Lima bean was intercropped with maze respectively (Table 4).

The result indicated that number of productive cobs of maize per plant was decreased with increasing density of lima bean in intercropping system. The highest number of cobs might be from the low competition of companion crops caused from optimum population density within the system. Because the greater plant density reduces light interception per plant and it is likely that mutual shading affect source capacity to supply a second ear with photo assimilate. The same result was reported by Sarquis *et al*. (1998) who found that plant density strongly influences the rate and duration of crop growth and ultimate fate of multiple ears. They found that a 30% reduction in light interception by the canopy during the crop growth cycle was enough to completely suppress the development of a second ear. Similarly, maize and faba bean densities were significantly affects maize cob number in intercropping (Chianeh *et al*., 2011). In contrary, Makgoga (2013) reported the highest number of maize cobs per plant when intercropped with dry bean followed by optimum population. He further suggested that intercropping maize with dry bean benefitted the maize plants. This contradiction might be due to varietal difference between Lima bean and dry bean, also might be because of their difference in growth habit.

4.2.2. Number of kernels per row

At both site, ANOVA results showed that number of kernels (seeds) per row was highly significantly (P<0001) affected by component population density (Table 4 and Appendix 3 and 4**)**. The maximum number (52.75) of kernels (seeds) per row was recorded by sole maize followed by (44.8 and 43.9) recorded from maize intercropped with 20,515 and 26,666 ha^{-1} (Table 4) respectively, at Seka, whereas the lowest seeds number per row (33.8) was recorded by maize intercropped with 38,095 ha^{-1}. 49.3and 31.3 kernels per rows were recorded at Dimtu site which received similar treatment with Seka site (Table 4). The maximum seed number might be due to the low competition of crops and the lowest caused from the high competition of crops for nutrient and moisture that leads to decrease in vigor cob to bear high seeds; this indicates inverse relationship between plant density and number of kernels per plant because of competition for growth resource.

Similarly, Buren *et al*. (1994) reported that at the low plant density the number of plants limit yield because of few cobs produced, whereas at high plant density yield is limited by the number of unproductive plants and a decrease in number of kernels per ear (Hashemi-Dezfouli and Herbert, 1992). Francis *et al*. (1982) reported that, the kernels per cob differences in crop mixture are influenced by densities and spatial arrangement of crops and levels of resource availability caused crop competition within the co-existing crops. In contrary, Tolera (2005) reported non-significant effects of climbing bean population density in maize- climbing bean intercropping experiment on number of kernel per row might be due to the difference included varieties of bean in their study.

Table 4 Maize Yield and Yield Components under maize-Lima bean intercropping at Seka and Dimtu as the result of LB densities.

Locations	Treatments	Yield components and Yield parameters							
		Number of cobs per plant	Cob Length (cm)	Number of rows per cob	Number of kernels per row	100 Seed Weight (g)	Grain yield (t ha^{-1})	Dry biomass (t ha^{-1})	Harvest index (%)
Seka	Sole maize	1.53^{a}	50.12^{a}	14.0^{ns}	52.75^{a}	44.14^{a}	5.73^{a}	32.2^{a}	18.0^{b}
	Sole Lima bean	-	-	-	-	-	-	-	-
	LB spaced at 35cm and intercropped with M	1.03^{c}	44.6^{c}	12.90^{ns}	33.8^{c}	34.8^{c}	4.18^{c}	26.96^{b}	15.5^{b}
	LB spaced at 50cm and intercropped with M	1.23^{b}	46.48^{bc}	13.30^{ns}	43.9^{b}	38.47^{bc}	4.78^{b}	20.49^{c}	23.3^{a}
	LB spaced at 65cm and intercropped with M	1.28^{b}	47.875^{b}	13.85^{ns}	44.8^{b}	39.34^{b}	4.83^{b}	18.8^{c}	25.9^{a}
LSD (5%)		0.1491	1.8066	2.3629	0.9452	4.9444	4.1322	0.4381	4.3074
Dimtu	Sole maize	1.43^{a}	47.22^{a}	14.73^{a}	49.3^{a}	37.18^{a}	4.95^{a}	26.77^{a}	19.7^{b}
	Sole Lima bean	-	-	-	-	-	-	-	-
	LB spaced at 35cm and intercropped with M	1.10^{c}	42.69^{c}	12.80^{b}	31.3^{c}	26.17^{c}	3.8^{c}	23.67^{ab}	16.5^{b}
	LB spaced at 50cm and intercropped with M	1.27^{b}	44.55^{b}	13.46^{b}	42.17^{b}	30.9^{bc}	4.3^{b}	22.27^{bc}	18.4^{b}
	LB spaced at 65cm and intercropped with M	1.30^{b}	45.33^{c}	13.6^{b}	42.6^{b}	32.8^{abs}	4.53^{ab}	18.83^{c}	24.6^{a}
LSD (5%)		0.0942	3.0752	1.6638	1.0738	1.6316	6.0293	0.4929	4.3436

Means followed by the same letter within a column are not significantly different from each other at 5 % level of significant.

4.2.3. Maize Cob length

Analysis of result revealed that cob length of maize from both site (Seka and Dimtu) showed highly significant ($P<0.01$)**)** difference (Table 4 and Appendix 3 and 4) due to the Lima bean population density in their intercropping system. The maximum number of cob length 50.12 and 47.22 cm was recorded by sole maize at Seka and Dimtu site, respectively. The minimum length of cob 44.6 and 42.68cm, which was recorded from 35,095 ha^{-1} population of Lima bean when intercropped with maize at Seka and Dimtu respectively (Table 4).

The observed reductions in cob length as population of component crops were increased might be because of more density of Lima bean due to vigorous growth habit of the crop that leads to higher competition among crops to harvest light. Likewise, Madonni *et al*. (1998) who stated that decreased case solar radiation reduced both cob length and cob mass through reductions in biomass production. Similarly, Vasic *et al*. (2000) found that the highest ear length of maize was obtained in sole crop than intercrop. Furthermore, among plots with intercropping, the lower population density of Lima bean results greater cob length, this might be less competition for growth resource and complementary relation between companion crops. Also, Lulie *et al.,* (2016) common bean population density on maze cob length of maize and, agreed with Jibril *et al.,* (2015).

4.2.4. Hundred Seed weight:

At both study sites, the result revealed that hundred-seed weight of maize was significantly ($P\leq0.05$) affected by the population density of Lima bean intercropped with maize (Table 4 and Appendix 3 and 4).

Among intercropping treatments maximum (39.34 and 32.8g) mean hundred kernel weights was found when maize intercropped with 20,512ha^{-1} population density of Lima bean though statistically at par with 26,666ha^{-1}(38.47 and 30.9g) (Table 4) at Seka and Dimtu site respectively. While the minimum (34.8 and 26.17g) hundred seed weight was recorded from Dimtu and Seka site respectively, as maize intercropped with 38,095 ha^{-1} population density of Lima bean. The result of hundred seed weight indicates that as population density increased the seed weigh decreased. This might be due to relatively less competition for available resources at lower population densities which finally attributed formation of large seed size. The highest hundred kernel weight in sole maize planting from both sites could be due to large seed size in a very low plant population per unit area which could be attributed to large accumulation of assimilate.

Similarly, Lulie *et al*., (2016) found that population density of common bean had significant effect on hundred kernel weight of maize in maize-common bean intercropping system. Also, Undie *et al.*,(2012); Abraha (2013) noted that hundred seed weight of maize was higher in pure stand of maize than under maize/soybean mixtures. Likewise, Thobasti (2009) indicated the highest thousand-seed weight was recorded by sole crop than maize intercropped with cow pea cultivar.

4.2.5. Maize grain yield

The result showed that there were highly significant ($P<0.01$) differences in grain yield of maize due to the effect of the Lima bean population density (Table 4 and Appendix Table 3 and 4). However, among intercropping plots the greater grain yield (4.83 t ha^{-1}) was recorded when the lowest population density (20,512ha^{-1}) of Lima bean was intercropped with maize, and it was statistically par with maize grain yield (4.78t ha^{-1}) that obtained from 26,666ha^{-1} of lima bean when intercropped (Table 4) at Seka site. The minimum grain yield (4.18 and 3.8t ha^{-1}) was recorded when the highest density of Lima bean (38,095ha^{-1}) was intercropped at Seka and Dimtu respectively (Table 4). The result denotes that as population density of component crops in intercropping was closer to optimum, thus it minimizes competition among crop for growth resources also complementarity of component crops was better at optimum density. The result may be due to growth nature of this bean to climb and cover nearby crop, and agree with (Tolera *et al.*, 2005; Lulie *et al.*, 2016).

The maximum yield (5.73 and 4.95t ha^{-1}) was recorded from sole maize at Seka and Dimtu respectively. Comparing sole maize with intercropped maize the observed yield reduction by 19.8% at Seka and 14.9% at Dimtu, might be resulted from inter specific competition of component crops for nutrient and light because of unbalanced utilization between component crops. Similarly, Chemeda (1997) reported yield reduction of maize grain by 24% in intercropping of maize with common bean due to higher inter-specific competition for available resources such as nutrients, soil moisture and root spaces between component crops. Similarly, Davis and Garcia (1987) also get the same result in which the grain yield of intercropped maize with climbing bean was reduced by 494 kg/ha as compared to sole crop. Francis *et al*. (1982) reported that maize yield decreased by 31% when intercropped with climbing bean. On the other hand, the observed level of reduction on maize grain yield below 20% was tolerable for intercropping communities that might be because of the peak for nutrient demand of both crops was not overlapped; even it increases nitrogen fertilizer by nodules for maize.

4.2.6. Dry biomass yield of Maize

At both sites of this study, the effect of Lima bean planting density had significant ($P<0.05$) effect on maize's dry biomass yield of maize (Table 4 and Appendix Table 3 and 4). From intercropping plots the maximum dry biomass (26.96 and 23.67Qt ha^{-1}) was recorded when 38,095 ha^{-1} Lima bean density was intercropped with maize and the minimum 18.8 and 18.3Qt ha^{-1} was recorded (Table 4) when Lima bean population density 20,512ha^{-1} intercropped with maize at Seka and Dimtu site, respectively. Among intercropped plots, the maximum total biomass yield was recorded from the plot that receive higher component crop densities, in contrast the minimum total biomass yield of maize was recorded on the plot that gave maximum grain yield. The reason might be the absorbed nutrients by crop were transformed to grain yield and reduce the dry matter production. This result agrees with Ludlow and Muchow (1988) who stated that a higher transfer of assimilates to the grain would reduce the proportion of dry matter produced early in growth that may be left as a stover. They further described that assimilate remobilization tends to improve yield stability by acting as a defense against the effects of resource deficits on the current assimilation.

On the other hand at both study sites, sole cropping gave the highest (32.2 and 26.77 Qt ha^{-1}) dry biomass of maize than intercropping at Seka and Dimtu respectively (Table 4). Thus, the sole crop was superior to the intercrop by 31.63 and 19.35% at Seka and Dimtu respectively, which might be because of greater interspecific competition on the available limited growth resources by the intercropped than the sole crop. Similarly, Demesew (2002); Tolera (2003); Tsubo *et al.* (2003), reported that intercropping practice reduces dry matter accumulation in comparison with sole cropping. In the same way, the decrease in total plant biomass of maize under maize/cowpea intercropping had been reported by (Egbe *et al.,* 2010).

4.2.7. Harvest index

The effect of population density showed highly significant ($P\leq0.01$) variation on maize harvest index at both Seka and Dimtu site ((Table 4 and Appendix Table 3 and 4). The maximum (25.9 and 24.6%) harvest index of maize was recorded when recommended density of maize was intercropped with 20,512 ha^{-1} of lima bean from Seka and Dimtu respectively (Table 4).This might be due to lower competition from lower plant density resulting in increased partitioning of dry matter to the seed and reduced the amount of biomass, thus, harvest index had been increased under optimum density of component crops. In line with, Jibril *et al.,* (2015) stated that harvest index of maize showed significant effect due to component density of maize-common been intercropping experiment. Ludlow and Muchow also (1988) reported that higher transfer of assimilates to the grain would maximize the harvest index and reduce the proportion of dry matter produced early in growth that may be left as a stover.

4.3. Yield and Yield Components of Lima bean at Seka and Dimtu site

4.3.1. Number of pods per plant

Analysis of variance showed that component population density had highly significant ($P<0.001$) effect on number of pods per plant at both Seka and Dimtu site (Table 5 and Appendix Table 5 and 6). Among intercropped plots, the maximum number of pods per plant 37.78 was recorded by (20,512ha^{-1} Lima bean) in intercropping with maize and the lowest 32.68 was recorded by (38,098ha^{-1}) was intercropped at Seka site. Whereas, 43.3 and 36.53 was the maximum and minimum number of pods per plant recorded at Dimtu site when 20,512ha^{-1} and 35,095ha^{-1} Lima bean density were intercropped with maize respectively (Table 5).

This result showed that, number of pods per plant decreased with the increasing planting density. The reason for low number of pods during intercropping were, due to intra and interspecific competition of the crops leading to low number of effective branches that can give greater number of pods. Similarly, Turk *et al.* (2003) confirmed that number of pods per plant was adversely linked to plant density. Also, Adem (2006) found that number of pods per plant was significantly affected by planting density of Common bean in maize/common bean and by planting density of cowpea in sorghum-cowpea intercropping.

Moreover, the overall highest pods per plant (44.83 and 55.08) was recorded when averaged sole Lima bean, while the lowest (35.9 and 40.8) was recorded when averaged intercropped plots (Table 5) at Seka and Dimtu site respectively. This result might be due to higher leaf area in sole bean that led to increased photosynthetic capacity of the crops. Reduction in number of pods per plant at higher density per unit area was credited to increased competition among plants for light, nutrient and other commonly used for growth, which might to end with reduced the number of active branches that contributes for the number of pods per plant. This also corroborates with Ghosh (2004) stated pod yield of groundnut were lower in groundnut-cereal (maize, sorghum, and pearl millet) intercropped than in monoculture. Also, Abraha (2013) detailed that intercropping significantly affected number of pods per plant where the higher was recorded by sole cropped and lower was recorded by intercrop averages. Reduction in number of pods due to intercropping was also reported by Yayeh (2014) who found that the overall highest lupine pod/plant were remarkably greater in sole lupine cropping system as compared to intercropped with wheat, barley and finger millet.

4.3.2. Number of seeds per pod

The number of seeds per pod revealed highly significant ($P<0.01$) variation by the effects of population density (Appendix Table 5 and 6) at both site of this study. Among intercropped plots 3.3 and 2.9 was the maximum and minimum number of seeds per pod recorded from T_5 which was statistically the same with T_4 (3.2) and T_3 respectively at Seka site (Table 5). Similarly, from Dimtu experimental site 2.53 and 1.9 was the highest and lowest numbers of seeds per pod (Table 5) recorded from T_5 and T_3 i.e. when 20,512ha^{-1} and 38,095ha^{-1} density of lima bean was intercropped with maize respectively at Dimtu. The reduced number of seeds per pod in intercropped plots could be as a resulted from the effect of planting density. The same result was reported by Yesuf (2003) on sorghum-haricot bean; Adem (2006) on sorghum-cowpea intercropping found significantly reduced pod per plant and seeds per pod were seen as a result of negative effect of planting density.

The overall highest seeds per pod 3.7 and 3.6 were recorded from sole Lima bean at Seka and Dimtu respectively (Table 5), whereas the lowest 3.1 and 2.2 was recorded by average intercropped plots at Seka and Dimtu site respectively. The higher number of seeds per pod in sole lima bean might be due to greater inter-specific competition most likely for soil moisture, nutrient and light in intercropping system. Similarly, Kheroar and Patra (2013) reported that number of seeds per pod was significantly reduced in green gram, black gram, soybean and ground nut due to intercropping. In covenant with Niringiye *et al.* (2005) revealed that, values for number of seeds per pod and mean grain weight intercrops were somewhat lower than in sole crop.

4.3.3. Lima bean Pod length

Statistically significant (P<0.05) variation were observed in pod length due to component population density under maize-lima bean intercropping system (Table5 and Appendix Table 5 and 6). Among intercropping plots at Seka site 11.21 and 8.45cm (Table 5) was the maximum and minimum pod length was recorded from 20,512 and 26,666 ha^{-1} respectively. The recorded result from Dimtu site showed that 14.96 and 11.9 was the maximum and minimum length of pods recorded from 20,512 and 38,095 ha^{-1} respectively. The higher the number of pods per plant and number of seeds per pod in the sole crops due to lower competition contributed for the highest pod length in the sole crop, the result agreed with (Yesuf, 2003).

Additionally, when we compare sole and intercropped lima bean for pod length, maximum pod length 13.19 and 16.9cm was recorded by mean sole Lima bean, while the minimum 10.4 and 13.63 was recorded from mean intercropped plots at Seka and Dimtu respectively (Table 5). Definitely, the main reason for this lower pod length of the intercropped Lima bean plants may possibly due to the higher plant population per unit area of the component crops that could compete for the scarce resources commanded to reduce the pod length of the bean plant. In agreement with Thobasti, (2009) found cowpea cultivar 'Agriwana' intercrop produced the shortest pod length and there was significance reduction in pod length in intercropping condition. Similarly, Jibril *et al.,* (2015) stated that common bean varieties under intercropping with maize produced the shortest average pod length 12.5 cm and there were significant reduction in pod length under intercropped plots.

4.3.4. Hundred seed weight:

Analysis of variance showed that the effect of component density had highly significant (P<0.01) effects on 100 seed weight (Table 5 and Appendix 5 and 6). The maximum 100 seed weight 61.34g and 76.63g was recorded when maize intercropped with 20,215ha^{-1} Lima bean density at Dimtu and Seka respectively. The minimum 100 seed weight 51.5 and 62.9g was recorded when 38,095ha^{-1} Lima bean density intercropped with maize at Dimtu and Seka respectively (Table 5). This result showed that 100 seed weight was increase as Lima bean decrease in population density in intercropping plots. Similarly, Turk *et al*. (2003) reported that the lowest plant density produced the highest seed weight. Adem (2006) reported that the highest hundred seed weight of intercropped cowpea was obtained from a planting ratio of sorghum 100%*25% cow pea than sorghum 100% * 50% cowpea.

The maximum hundred seed weight 71.9 and 83.8gm were obtained from sole crop Seka and Dimtu site respectively (Table 5). The result might be because of the nitrogen that fixed by sole beans might not absorbed by other crop, rather it was used by bean itself that leads to higher hundred seed weight, since the fixed nitrogen by lima bean was not competed by maize in sole bean enough assimilate could be translocate to filled the seed. Reverse was true in case of intercropping which means the reduced result of hundred seed weight in intercropped plots might be because of the nitrogen that fixed by lima bean could be used by maize crop. Demesew (2002) also reported similar result from the intercropping of maize with bush bean. In agreement with Jibril *et al.,* (2015) stated similar report where the maximum (51.49) hundred seed weight was recorded from sole crop as compared to the minimum (49) mean value recorded on intercropped plot.

4.3.4. Seed yield:

Results revealed that lima bean grain yield was highly significantly ($P<0.01$) affected by component plant population (Table 5 and Appendix 5 and 6) at both experimental sites. Among intercrops the maximum grain yield 17.3 and 19.0 Qt ha^{-1} was recorded from 20,215 ha^{-1} lima bean density intercropped with maize at Seka and Dimtu respectively. The minimum grain yield 13.1 and 12.4 Qt.ha^{-1} which was recorded from 38,095 ha^{-1} lima bean density intercropped with maize at Seka and Dimtu respectively (Table 5). The high population of the bean and maize component crops per unit area of land might cause crops to compete with each other for growth resources like nutrient and light that leads to decreased yield of co-existing crops. Also, Chianeh *et al*. (2011) showed that the interaction effects of maize and faba bean densities on grain yield of faba bean was significant, and there was a general reduction in the yield of faba bean under intercropping system.

Overall, the maximum 21.18 and 27.3Qt ha^{-1} was recorded from sole Lima bean at experimental site of Seka and Dimtu respectively, whereas 14.7 and 15.7 Qt. ha^{-1} was the recorded average intercropped yield of lima bean, thus depressed yield was observed from intercropped plots. This might be because of lower competition ability of lima bean leads to be be dominated by maize for limited growth resource most probably for solar radiation which affected the rate of photosynthesis and thereby translocation of sugar from source to sink. Similarly, Pal *et al*. (1993); Niringiye *et al*. (2005) Kheroar and Patra (2013); revealed that yield of intercropped legumes was reduced by intercropping with maize that caused due to receipt of lower amount of solar radiation..

Table 5 Lima bean Yield components and Yield under maize-Lima bean intercropping at Seka and Dimtu site

Locations	Treatments	**Yield components and Yield of Lima bean**				
		Number of pods per plant	Number of seeds per pod	Pod length (cm)	100 seed weight (g)	Lima bean grain yield (Qt ha^{-1})
Seka	Sole maize	-	-	-	-	-
	Sole Lima bean	44.83^{a}	3.7^{a}	13.19^{a}	71.90^{a}	21.18^{a}
	LB spaced at 35cm and intercropped with M	32.68^{c}	2.9^{c}	8.45^{c}	51.50^{c}	13.1^{c}
	LB spaced at 50cm and intercropped with M	37.37^{b}	3.2^{bc}	10.98^{b}	53.93^{bc}	13.8^{bc}
	LB spaced at 65cm and intercropped with M	37.78^{b}	3.3^{b}	11.21^{b}	61.34^{b}	17.3^{b}
LSD (5%)		3.409	0.3638	1.2361	9.1238	3.6133
Dimtu	Sole maize	-	-	-	-	-
	Sole Lima bean	55.08^{a}	3.60^{a}	16.9^{a}	83.8^{a}	27.3^{a}
	LB spaced at 35cm and intercropped with M	36.53^{c}	1.93^{c}	11.9^{c}	62.9^{c}	12.4^{c}
	LB spaced at 50cm and intercropped with M	42.6^{b}	2.13^{bc}	14.03^{bc}	69.8_{bc}	15.8^{bc}
	LB spaced at 65cm and intercropped with M	43.3^{b}	2.53^{b}	14.96^{ba}	76.63^{ba}	19.0^{b}
LSD (5%)		5.55	0.42	2.76	10.87	6.49

Means followed by the same letter within a column are not significantly different from each other at 5 % level of significant.

4.4. Maize-Lima bean intercropping System productivity

Among different indices proposed to assess productivity of intercropping system as all, land equivalent ratio and companion crops equivalent yield (maize and lima bean equivalent yield) were used to evaluate productivity of Lima bean-maize intercropping system in this study.

4.4.1. Land equivalent ratio:

The population density of Lima bean in an intercropping showed highly significant ($P \leq 0.001$) on total land equivalent ratio (LER) (Table 6 and Appendix Table 7 and 8). The total LER in all intercropped plots were more than unity (Table 6). This justifies mutualistic and complementarity of the two component crops. Thus, intercropping of Lima bean with maize is more advantageous than sole cropping of maize and Lima bean. The greater total LER 1.68 and 1.63 were recorded when maize is intercropped with 20,512ha^{-1} lima bean density at Seka and Dimtu respectively. The lowest 1.39 and 1.23 at Seka and Dimtu was recorded when maize is mixed with 38,095ha^{-1} lima bean respectively (Table 6).

Intercropped treatments had a mean total LER value of 1.51 at Seka and 1.45 at Dimtu (Table 6) that was greater than sole crop. These values indicated that intercropping gave 51 and 45% yield advantages at Seka and Dimtu respectively, thus it increases land use efficiency than planting sole crops of each component crop. This could be happened due to the efficient utilization of growth resource by the intercropped and/or could be due to the intercropping advantages of weed reduction, nitrogen fixation and the increased light use efficiency. Similarly, Tolera *et al*. (2005) observed more yield and higher land use efficiency by intercropping of maize with climbing bean. Consequently, Tsubo *et al.* (2004) the intercropping maize-bean system was more effective and more efficiently used land relative to the separate planting. In line with, Willey and Osiru (1972) reported that 38% yield advantage was obtained when beans intercropped with maize. Also, Chemeda (2003) found, up to 28% higher total productivity of maize-bean intercropping.

4.4.2. Maize and Lima bean equivalent yield

Analysis of result on Maize and lima bean equivalent yield were significantly ($P<0.5$) recorded to be higher in all intercropping systems with respect to pure stand yield of their corresponding sole crops yields (Table 6 and Appendix Table 7 and 8) at both sites. The highest maize equivalent yields 7.95 t ha^{-1} at Seka and 8.0 t ha^{-1} at Dimtu (Table 6), whereas the highest lima bean equivalent yield 4.4 t ha^{-1} at Seka and 4.3 t ha^{-1} at Dimtu were recorded by LB spaced at 65cm and intercropped with M. This result indicated that 27.9 and 62% was the yield advantage of maize covered by intercropping with Lima bean at Seka and Dimtu respectively. Whereas, 51.13 and 37.21% was the yield advantages of lima bean covered at Dimtu site respectively (Table 6). Such yield advantage might be due to combined yield of both crops. This is consistent with studies by Cardoso *et al*. (2007) who found higher maize equivalent yield relative to sole-cropped maize in maize-common bean intercrop system. Further they stated that maize equivalent yield was 28% higher on maize-common bean intercrop with single row IPA relative to sole-cropped maize. Similarly, Chalka and Nepalia (2005) also observed that introduction of different legume crops significantly increased maize equivalent yield. Also, Khan *et al.*, (2018) reported the yield advantages of 147% (maize) and 18 % (garden pea) under maize-garden pea intercropping over their respective sole crops.

Table 6 Productivity of maize-Lima bean intercropping system as affected by population densities of Lima bean at Seka and Dimtu sites

Location	Treatment	Land Equivalent Ratio		Total LER	Cop Equivalent yield (t/ha)	
		Maize	Lima bean		MEY	LBEY
Seka	Sole maize	1.00^{a}	-	1.00^{c}	5.73^{d}	_
	Sole Lima bean	-	1.00^{c}	1.00^{c}	_	2.15^{c}
	LB spaced at 35cm and intercropped with M	0.75^{c}	0.64^{c}	1.39^{b}	6.53^{c}	3.65^{bc}
	LB spaced at 50cm and intercropped with M	0.83^{bc}	0.65^{c}	1.48^{b}	7.28^{b}	4.03^{ab}
	LB spaced at 65cm and intercropped with M	0.85^{b}	0.83^{b}	1.68^{a}	7.95^{a}	4.40^{a}
LSD (5%)		0.0854	0.1656	0.1411	0.4726	0.37
	Sole maize	1.00^{a}	-	1.0^{c}	4.96^{cd}	-
Dimtu	Sole Lima bean	-	1.0^{a}	1.0^{c}	-	2.7^{c}
	LB spaced at 35cm and intercropped with M	0.79^{c}	0.45^{c}	1.23^{b}	6.2^{bc}	3.4^{b}
	LB spaced at 50cm and intercropped with M	0.90_{b}	0.59^{bc}	1.47^{a}	7.3^{ab}	4.0^{ba}
	LB spaced at 65cm and intercropped with M	0.92^{ab}	0.70^{b}	1.63^{a}	8.0^{a}	4.3^{a}
LSD (5%)		0.0811	0.2422	0.2209	1.2	0.65

Means followed by the same letter within a column are not significantly different from each other at 5 % level of significant. LER, MEY and LBEY represents Land equivalent ratio, Maize equivalent yield and Lima bean equivalent yield respectively.

4.5. Influence of Intercropping on Soil Properties

Soil pH: Analytical results of soil samples collected after harvest indicated that soils are in acidic range, and the pH level showed non-significant (P>0.05) difference in all treatments at both study area (Table 7 and Appendix table 9 and 10). The soil samples under sole and intercropped treatments were also under similar pH values of 5.65 and 5.3 at Seka and Dimtu respectively (Table 7) implying that the intercropping of maize and lima bean did not influence the pH values of the soil. Similarly, Ariel *et al.* (2013) reported that pH values of the rhizosphere soil remained statistical during the cropping cycles of intercropping maize with soybean. In contrary, Ossom and Rhykerd (2007) have reported that sole field bean had greater effect in raising the soil pH over pure maize. Additionally, Lulie *et al*., (2016) reported that when sole and intercropped treatments were carried out on the soil with similar pH values, cropping systems did not influence the pH values of the soil.

Organic Carbon and Total N:

The organic carbon and nitrogen contents of the soil did not significantly (P>0.05) affected among varied planting densities of lima bean in intercropping with maize (Table 7 and Appendix table 9 and 10). However, the trends of data showed that numerically intercropping treatments had higher total N than sole treatments (Table 7). Even though all treatments were statistically par, the highest total N (0.2) was recorded from intercropped plots at both sites of this study. The improvement of soil N under intercropped plots could be due to a possibility of root exudates or the decay of roots and nodules causing the release of N from the legume components into the rhizosphere during the cropping season (Szumigalski and Van, 2006).

Comparing the soil analytical results before planting and after harvest, the total N decreased both under sole and intercropped plots (Table 7). Contrarily, the expected greater N content of intercropped treatments due to the contribution of N to the rhizosphere by the legumes root from atmospheric fixation was not meet. This might be due to the unstopped growth nature of lima bean variety used in the study. This means as the crop stops flowering at the end of final harvest the partial parts of the plant continue to live with lower growth rate and then still it uses previously fixed and/or available soil nitrogen. Accordingly, Ofori and Stem (1987) stated that the variations in N fixation under legume cereal intercropping systems depend on genotypes, plant morphology, density of component crops and type of management. The present study also in line with Santalla *et al.* (2001) who reported that exudates produced by maize may increases in nodulation leading to better N under intercropped treatments; this might be because of varietal difference.

On the other hand, the organic C content of the soil was not significantly ($P>0.05$) affected in this study at both sites (Table 7 and Appendix 9 and 10). Further, the organic C content decreased during the growth period despite the release of exudates and supply of mucilage layer indicating high decomposition by microorganisms. Similar observation was also made by Ossom and Rhykerd (2007).

Available phosphorous:

Available phosphorous was non-significantly ($P>0.05$) affected by population densities of lima bean at Seka (Table 7 and Appendix Table 9). Soil samples collected from 20,512ha^{-1} (least population density of lima bean in the experiment) had higher numerical P levels than others though it was statistically at par with all treatments (Table 7). However, the trend was inconsistent to give further justification. Even though analysis of variance showed as the all treatments were statistically par, available P content of the Seka site experimental soil (4.43 mg kg^{-1}) at planting declined to 2.4, 1.9 and 1.7 mg kg^{-1} after harvesting under sole cropping of maize, sole lima bean and mean intercropping respectively (Table 7).

On the other hand, when we see as whole, available phosphorous was showed slightly significantly ($P<0.05$) affected by population densities of lima bean at Dimtu. But all intercropped plots are statistically par (Table 7 and Appendix Table 10). In this experimental site the available P content of the experimental soil (3.76 mg kg^{-1}) at planting declined to 3.6, 1.3 and 1.5mg kg^{-1} after harvesting under sole cropping of maize, sole lima bean and mean intercropping respectively (Table 7). The observed reduction of soil available P might be due to removal of soil P by grains and other plant parts. Legumes including Lima bean have high P requirements due to the need for high amount of P in the process of N_2 fixation and the production of protein containing compounds, and hence P concentration in legumes is generally much higher than that of cereals. Similarly, Mandal *et al.*, (2014) showed that available P content was significantly reduced in post-harvest soils of all plots in which maize was intercropped with soybean and groundnut at varying row proportion compared to the initial and sole maize.

Table 7 Selected soil physical and chemical properties of Seka and Dimtu experimental site before planting and after harvesting in 2022 cropping season

Locations	**Treatments**	**pH**	**Total N (%)**	**Organic C (%)**	**Available P. (mg kg^{-1})**
	Before planting	5. 65	0.19	2.22	4.43
	After harvest				
	Sole maize	5.55	0.18	2.1	2.4
	Sole Lima bean	5.5	0.17	2.0	1.9
	LB spaced at 35cm and intercropped with M	5.3	0.17	2.1	1.6
Seka	LB spaced at 50cm and intercropped with M	5.5	0.20	2.2	1.5
	LB spaced at 65cm and intercropped with M	5.5	0.16	2.1	2.0
LSD (5%)		NS	NS	NS	NS
	Before planting	5.3	0.2	1.5	3.76
	After harvest				
	Sole maize	5.25	0.2	2.4	3.6^{a}
	Sole Lima bean	5.48	0.195	2.4	1.3^{b}
Dimtu	LB spaced at 35cm and intercropped with M	5.22	0.20	1.8	1.3^{b}
	LB spaced at 50cm and intercropped with M	NS	NS	NS	1.5^{b}
	LB spaced at 65cm and intercropped with M	5.27	0.19	2.3^{ns}	1.8^{b}
LSD (5%)		NS	NS	NS	2.05

Means followed by the same letter within a column are not significantly different from each other at 5 % level of significant. NS= non-significant**.**

4.6. Correlation Coefficient between Yield Components of maize and lima bean under Maize/lima bean intercropping at Seka and Dimtu Site

Maize:

A Pearson correlation analysis was performed to determine the relationship between the number of cobs per plant, cob length, maize grain yield, dry biomass and harvest index of maize for both sites of this study (Table 8 and 9). As all, a positive and significant correlation (r) was found to exist between number of cobs per plant and other characters such as cob length (r= 0.71), hundred seed weight (r= 0.82), maize grain yield (r=0.76), whereas number of cobs per plant was positively and non-significantly correlated with dry biomass (r =0.4) and harvest index (r=0.1) of maize at Seka (Table 8 (a). Also, a positive and significant correlation was found between cob length and number of cobs per plant (r= 0.71), 100 seed weight (r=0.82), maize grain yield (r= 0.77); whereas positively and non-significantly correlated with dry biomass (r=0.27) and harvest index (r= 0.28) of maize. Likewise dry biomass was positively and significantly correlated with all yield components of maize (Table 8), except with harvest index, which is negatively and significantly correlated with dry bio mass (r= -0.82). Similarly hundred seed weight was positive and significantly correlated with other yield components of maize except with harvest index that was negative and non-significantly correlated with 100 seed weight Table 8.

Similarly, at Dimtu sites of this study analyzed results of a Pearson correlation found that a positive and significant correlation (r) was found to exist between number of cobs per plant and cob length (r=0.85), hundred seed weight (r= 0.75), whereas positive and non-significantly correlated with maize grain yield (r=0.48), dry biomass (r= 0.24) and harvest index (r= 0.16) of maize (Table 8(b). Also, maize cob length was positive and significantly correlated with hundred seed weight(r= 0.77) and maize grain yield (r= 0. 66), while positive and non-significantly correlated with dry biomass (r= 0.35) and harvest index (r= 0.19) Hundred seed weight was non-significant and positively correlated with maize grain yield (r=0.59), dry biomass (r=0.36) and harvest index (r=0.15). Maize dry biomass was negatively and significantly correlated with harvest index (r= -0.69) at Dimtu site (Table 8).

Table 8. Correlation Coefficient between Yield Components of maize under Maize-lima bean intercropping at Seka and Dimtu Site

Locations													
Seka							**Dimtu**						
Pearson Correlation Coefficients, N = 16 Prob > |r| under H0: Rho=0							**Pearson Correlation Coefficients, N = 12** Prob > |r| under H0: Rho=0						
#####	NCPP	CL	HSW	MGY	DBM	HI	#####	NCPP	CL	HSW	MGY	DBM	HI
#####							#####						
NCPP	1.00	0.71**	0.81***	0.77***	0.40 Ns	0.10 Ns	NCPP	1.00	0.86***	0.75**	0.48Ns	0.24 Ns	0.16 Ns
CL		1.00	0.45Ns	0.99***	0.27 Ns	0.27 Ns	CL		1.00	0.77**	0.66*	0.35 Ns	0.19 Ns
HSW			1.00	0.56**	0.46 Ns	-0.05Ns	HSW			1.00	0.59*	0.36 Ns	0.15 Ns
MGY				1.00	0.4 Ns	0.19 Ns	MGY				1.00	0.18 Ns	0.58*
DBM					1.00	-0.8***	DBM					1.00	-0.69**
HI						1.00	HI						1.00

Ns= non-significant, **= significant at 5 %, **= significant at 1%, ***= significant < 0.1%,* NCPP= number of cobs per plant, CL= cob length, HSW= hundred seed weight, MGY= maize, rain yield, DBM= dry biomass HI=harvest index.

Lima bean:

A Pearson correlation analysis was performed for Seka and Dimtu site to determine the relationship between the numbers of seeds per pods, pod length, hundred seed weight and lima bean grain yield at Seka and Dimtu site of this study (Table 9). As all, a positive and significant correlation (r) was found to exist between number of pods per plant and other characters such as number of seeds per pods (r= 0.55), pod length (r=0.67), 100 seed weight (r= 0.80), and lima bean grain yield(r= 0.68) at Seka site Table 9(a). Number of seeds per pods was positive and significantly correlated with pod length (r= 0.87), 100 seed weight (r= 0.67), and non-significantly relation was found between number of seeds per pods and lima bean grain yield (r= 0.45) at Seka site (Table 9).

Similarly, analysis a Pearson correlation for Dimtu site's lima bean yield parameters showed that a positive and significant correlation (r) was found to exist between number of pods per plant and other yield traits like as number of seeds per pods (r= 0.91), pod length (r=0.79), hundred seed weight (r=0.74), and lima bean grain yield (r= 0.77) at Dimtu site (Table 9). Number of seeds per pods was positive and significantly correlated with pod length (r= 0.74), hundred seed weight (r= 0.77), and non-significantly relation was found between number of seeds per pods and lima bean grain yield (r= 0.86) at Dimtu site (Table 9). Lima bean pod length also found to be correlated significant and positively with hundred seed weight (r= 0.78) and lima bean grain yield (r= 0.68). Correlation between hundred seed weight and lima bean grain yield (r= 0.64) was also positive and significant at Dimtu site (Table 9).

Table 9 Correlation Coefficient between Yield Components of Lima bean under Maize-lima bean intercropping at Seka and Dimtu Site

Locations											
Seka						Dimtu					
Pearson Correlation Coefficients, N = 16 Prob > |r| under H0: Rho=0						**Pearson Correlation Coefficients, N = 12** Prob > |r| under H0: Rho=0					
####	NPPt	NSPP	PL	HSW	LBGY	#####	NPPt	NSPP	PL	HSW	LBGY
NPPt	1	0.55*	0.67**	0.80**	0.68**	**NPPt**	1.00	0.91***	0.79***	0.74**	0.77**
NSPP		1	0.87***	0.67***	0.44Ns	**NSPP**		1.00	0.74**	0.77**	0.86***
PL			1	0.75***	0.59*	**PL**			1.00	0.78**	0.68**
HSW				1	0.59*	**HSW**				1.00	0.64*
LBGY					1	**LBGY**					1.00

Ns= non-significant, *= *significant at 5 %*, **= *significant at 1%*, ***= *significant < 0.1%,*
NPPPt = number of pods per plant, NSPP= number of seeds per plod, PL= pod length, HSW= hundred seed weight, LBGY= lima bean grain yield

5. SUMMARY AND CONCLUSION

The growing human population and time to time shrinking of arable land commanded to practice of mixed cropping in Jimma area, south western Ethiopia. Inclusion of Lima bean (neglected crop in Ethiopia) in cropping system particularly in mixed cropping with cereals like maize or sorghum is needed not only to save stalking materials but also, has multidirectional advantage (added source of income and nutrition for poor farmers, greenness of farm land relatively for longer time as the bean have longer life cycle helping for protection of soil from erosion), thus contributing for sustainability of land productivity.

Maize-Lima bean intercropping practices are done with purpose of creating a system with higher collective yield that could benefit the farmers and enhance crop diversity as well as reduce total crop failure. Planting density is one of obligatory agronomic decisions while practicing the intercropping system. Therefore, the study was conducted to define productivity of Maize-Lima bean intercropping system by determining optimum planting density of Lima bean in intercropping with maize for greater yield and yield components of the associated crops and best productivity of the system at both target area (Seka and Dimtu) of Jimma zone, southwestern Ethiopia.

The result of this study clearly showed that, lima bean spaced at 65cm and intercropped with maize and/or lima bean spaced at 50cm and intercropped with maize could be recommended for intercropping in both experimental areas based on the observed land productivity in terms of land equivalent ratio and yield advantage that described as maize equivalent yield and lima bean equivalent yield.

Thus, increasing intercropping practice is used to maximize the grain yield from the same space at the same time and the system is more appropriate in terms of maintaining yield advantage of component crops. So far, no research work had been done on the cropping system and proportion of maize and lima bean productivity in the study area; so it needs further research on maize and lima bean intercropping combination that would maximize land productivity. In order to give a sound recommendation, further research is suggested on the selection of best compatible maize and lima bean proportions of planting density under intercropping.

Future direction:

- ⇒ There is need to explore and assess this approach covering maize and lima bean planting proportion, water and nutrients use efficiency in different seasons and contrasting environments over years.
- ⇒ Crop tissue analysis after harvest is needed to be tested to understand whether inclusion of lima bean in mixed cropping with maize can improve grain quality of maize or not.
- ⇒ Further studies are also needed to understand the nitrogen balance of maize-lima bean intercropping system.
- ⇒ Breeders are expected to modify the vining ability and/or plant height of Lima been variety used in this study to make it more compatible for mixed cropping with maize.

6. REFERENCES

Abdisa Gemeda. and Girma Aboma. 1999. Assessment of maize and haricotbean production under differint types of cropping system in Bako area. In maize production technology for the future: challenges and opportunities: proc. 6th eastern and southern Africa Regional maize conf., 21-25sept.1998 (CIMMY and EARO). Addis Ababa, Ethiopia. Pp: 260-263.

Abraha L., 2013.The effect of intercropping maize with cowpea and lablab on crop yield. *Herald J. Agric. and Food Sc. Res.* 2 (5): 156- 170 October, 2013.

Adem Mohammed. 2006. Effects of component density of striga resistant sorghum and cowpea and N rates on productivity of intercropping system in North Wollo, Ethiopia. MSc. Thesis, Alemaya University. Pp.91.

Agegnehu Getachew, Amare Ghizaw and Weldeyesus Sinebo. 2006. Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. *Europ. J. Agron*. 25: 202-207.

Ajala R., Awodun M. Adeyemo A. and Dada B. 2019.Assessment of Wood Ash Application on Yield Advantage Indices of Maize and Lima Beans in an Intercrop, Akure, Nigeria. Journal of Experimental Agriculture International, 34(1): 1-11

Akande, S. R. and Balogun, M. 2007. Evaluation and heritability studies of local Lima bean *(Phaseolus lunatus L.)* cultivars from South West Nigeria. Revista UDO Agrícola, 7**:** 22-28.

Akande, S. and Balogun, M. 2007. Evaluation and heritability studies of local Lima bean *(Phaseolus lunatus L.)* cultivars from South West Nigeria. Revista UDO Agrícola, 7**:** 22-28.

Alemayehu, Daba.; Shumi Deresa.; Afeta, T. 2018, Effect of variety and time of intercropping of common bean (Phaseolus vulgaris L.) with maize (Zea mays L.) on yield components and yields of associated crops and productivity of the system at Mid-Land of Guji, SouthernEthiopia. Adv. Crop. Sci. Tech. 6, 324. [CrossRef]

Andrews D.J., and A.H. Kassam. 1976. The importance of multiple cropping in increasing world food supplies. American Soc. Agron. 27:1-10.

Andueza-Noh, R. H., Martínez-Castillo, J. and Chacón-Sánchez, M.I., 2015. Domestication of small-seeded lima bean (*Phaseolus lunatus* L.) landraces in Mesoamerica: evidence from microsatellite markers. *Genetica*, 143(6):657-669. doi: 10.1007/s10709-015-9863-0

Ariel C.E., Eduardo O.A., Benito G.E., Lidia G. 2013. Effects of two plant arrangements in corn (*Zea mays* L.) and soybean (*Glycine max* L. Merrill) intercropping on soil nitrogen and phosphorus status and growth of World J. Agric. Sci. 076 component crops at an Argentinean Argiudoll. American J. Agric and For., 1(2):22-31.

Avcioglu R., Boberfeld WO., Soya H., Geren H., Beckmann E., 2003. Investigations on some yield and quality characteristics of second crops of *Vicia sativa* and *Trifolium*84 *resupinatum* and their mixtures with *Lolium multiflorum*, 7th Symposium Ergebnisse Deutsch-Turkischer Agrarforschung, Ankara, 24-30 March 2003, pp. 109-112.

Bandyopadhay, S.K. and R. De, 1986. Nitrogen relationship and residual effects ofintercropping with legumes. *J. Agric. Sc.,* 107: 629-632.

Banik, P., A. Midya, B.K. Sarkar and S.S. Ghose. 2006. Wheat and chickpea intercroppingsystems in an additive series experiment: advantages and weed smothering. *Eur. J. Agron.* 24: 325-332.

Baudoin, J.P., 2006. *Phaseolus lunatus*. pp. 141-146. In: Brink, M., Belay, G. and De Wet, J.M.J., 2006. Plant resources of tropical Africa 1: cereals and pulses. Wageningen, The Netherlands: PROTA Foundation.

Beets, W.C., 1982. Multiple Cropping and Tropical Farming Systems. Gofer, London,Britain and West views Press. Colorado, USA.Pp.1-23.

Belel, M.D., R.A. Halim, M.Y. Rafii, and H.M. Saud. 2014. Intercropping of maize with some selected legumes for improved forage production: a review. J. Agric. Sci. 6 (3):48-62.

Benti T., Kebede M., Legesse W., Mosisa W., and Leta T., (1997). Reflections on the Successful achievements of hybrid maize breeding program in Ethiopia. Pp 67-71.Bulletin No. 245, Addis Ababa, Ethiopia.

Birhane G., Bentayehu G., 1989. The maize mega-environments of Eastern and Southern Africa and germplasm development. In: J.K. Ransom, ed. Maize Productivity Gains Through Research and Technology Dissemination, 3-5 December 1988 Nairobi.Nairobi: CIMMYT-Nairobi. Pp. 197-211.

Brooker, R.W.; Bennett, A.E.; Cong,W.; Daniell, T.J.; George, T.S.; Hallett, P.D.; Hawes, C.; Iannetta, P.P.M.; Jones, H.G.; Karley, A.J.; *et al*. 2015**.** Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. New Phytol.,206, 107–117. [CrossRef] [PubMed]

Broughton, W.J., Hernandez, G., Blair, M., Beebe, S., Gepts, P. and Vanderleyden, J., 2003. Beans (*Phaseolus* spp.)–model food legumes. *Plant and soil,* 252(1):55-128.

Buren, L.L, Mock, J.J. and Anderson, I.C., 1994. Morphological and physiological traits in maize associated with tolerance to high plant density. *Crop Sci*. 14, 426-429

Cardoso, E.J.B.N., Nogueira, M.A and Ferraz, S.M.G. 2007. Biological N2 fixation and mineral N in common bean–maize intercropping or sole cropping in southeastern Brazil. *Experimental Agriculture* 43: 319–330.

Carlson D. J., 2008. Intercropping with Maize in Sub-arid Regions. Community Planning & Analysis. Technical Brief. Pp. 1-6. April 16, 2008.

Carr, P. M., R. D., Horsley and W. W. Poland, 2004. Barley, oat and cereal-pea mixtures as dry land forages in the Northern Great Plains. *Agron. J.*, 96: 677- 684.

Central statistical Agency CSA, 2019. Report on Area and Production of major Crops. Stat. Bull.532. Pp. 1-125.

Chalka, M. K. and V. Nepalia. 2005. Production potential and economics of maize intercropped with legumes as influenced by weed control. *Indian J. Agron*., 50 (2):119-120.

Chemeda Fininsa. 1997. Effect of planting pattern, relative planting date and intra-row spacing on a haricot bean-maize intercrop. *Afri. Crop Sci. Soci*., 5(1):15-22.

Chemeda Fininsa. 2003. Relationship between bacterial blight severity and bean yield loss in pure stand and bean-maize intercropping systems. *Interna. J. of pest management,* 49(3): 177-185.

Chui JAN, Shibles R. 1984. Influence of spatial arrangements of corn on performance of an associated soybean intercrops. Field Crop Research 8, 187-198.

Daisy, E.K. 1979. Food legumes: TPI crop product digest. *Tropical Product Institute Circular*, pp 716.

Davis, J. H. C. and S. Garcia, 1987. Competitive ability and growth habit of indeterminate beans and maize for intercropping. *Field Crops Res.*, 6: 59-75.

Dean L. and Olsen S. 1965. Phosphorus in: Methods of Soil Analysis. In: Black C., (ed). *American society of Agronomy.* Madison, Wis.USA. pp 1035-1048.

Debouck, D.G., Maquet, A., Posso, C.E., 1989. Biochemical evidence for two different gene pools in lima beans, *Phaseolus lunatus* L. Bean Improvement Cooperative. Annual Report (USA) **(32)**:58-59.

Dewis J. and Freitas, P. 1975. Physical and chemical methods of soil and plant analysis.

Dhima K., Lithourgidis A., Vasilakoglou I. and Dordas C. 2007. Competition indices of common vetch and cereal intercrops in two seeding ratio. *Field Crop Res.* 100: 249-256.

Donald C. 1962. In search of yield. Journal of Australian Institute of Agricultural Science, 28: 171-178.

Dume Bayu, Gezahegn Berecha and Solomon Tulu 2015. Characterization of Biochar Produced at Different Temperatures and its Effect on Acidic Nitosol of Jimma, Southwest Ethiopia. Int. J. Soil Sci., 10 (2): 63-73.

EBI (Ethiopia biodiversity institute).2012. Third country report on plant genetic resources for food and agriculture.

Edward S. Buckler and Natalie M. Stevens, 2005, Maize Origins, Domestication, and Selection. *Field crops Res.,2(13):109-118.*

Egbe O., Alibo S. and Nwueze I. 2010. Evaluation of some extra-early and early maturing cowpea varieties for intercropping with maize in Southern Guinea Savanna of Nigeria. *Agriculture and Biology Journal, 1:845-458.*

Enyi, B.A.C., 1973. Effect of intercropping maize or sorghum with cowpeas, pigeon peas or beans. *Experimental Agric.*, 9: 83-93.

Erickson, H.T. 1982. Lima bean legacy. *Hort. Science* 17(5): 702-702.

Ethiopia Commodity Exchange Authority, 2019. A Review of supply and Marketing issues. Ethiopia, Addis Ababa.Pp.39.

FAO (Food and Agricultural Organization). 2013. Food and Agriculture Organization. www.fao.org (accessed date 12 May 2023).

FAO (Food and Agriculture Organization of the United Nations). 2008. FAO fertilizer andPlant nutrition bulletin: Guide to laboratory establishment for plant nutrient analysis. FAO, Rome Italy, 203p.

FAO, 2007. FAO Statistical Databases. (Online). Available at: *http:// fao stat. fao. Org /default*. Aspx. Accessed 1 August , 2022.

FAO, 2017. World Agricultural Production.[online] Available at: *http://faostat.fao.org/* default.aspx. Accessed 14 April. 2024.

Francis, B., Taye K., K. Shalander, O. Julius, A.P Efrain and Africa Z., 2000. Natural Resources under Threat: Analysis of farming systems of Ghimbo Woreda, Kefa-Sheka zone, Ethiopia. Working Document series no. 84. ICRA, Wagening, the Netherlands.

Francis, C.A., Parger M. and Tejada G., 1982. Density interaction in tropical intercropping Maize and climbing beans. *Field crops Res.*, 5: 164-176.

Gardiner, T. R. and L. E. Craker, 1981. Bean growth and light interception in bean maize intercrop. *Field Crop Res.*, 4: 313-320.

Genet, W.; Lulie, B.; Worku, W.; Beyene, S. 2016. Determinations of haricot bean (*Phaseolus vulgaris* L.) planting density and spatial arrangement for staggered intercropping with maize (*Zea mays* L.) atWondo Genet, Southern Ethiopia. Acad. Res. J. Agric. Sci. Res. 4, 297–320. [CrossRef]

Ghosh P. 2004. Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics of India. *Field crop Research 88:227-237*

Gomez A. and Gomez A. 1984. Statistical procedures for agricultural research. 2nd ed., Willey J. and Son I., New York, USA, PP: 97-107

Habtamu Admasu, Reddy M. L., Teshale Alemu. and Jibril Mohammed 1996. Maize based cropping system for sustainable agriculture in semi-arid area of Ethioppia. In: increasing food production through improved crop management: 1st inaugural conf. Agron crop physiol. Soc, Ethiopia, (eds Woldeyesus, S., T.zerihun and A. nugusie), Addis Ababa Ethiopia.

Harwood, R. R., P. Jeranyama, O. B. Hesterman and S. R. Waddington, 2000. Relay intercropping of sun hemp and cowpea to a small holder maize system in Zambia. *Agron*. *J*., 92:109-124.

Hashemi-Dezfouli, A & Herbert, S.J., 1992. Intensifying plant density response of corn with artificial shade. *Agron*. *J*. 84, 547-551.

Hellevang Kenneth 1995. Grain Moisture Content Effects and Management. North Dakota State Extension Publication AE-905. http://www.ag.ndsu.edu/extensionaben/ documents/ae905.pdf. [accessed Sep 2022.

Hobbs P.R., Sayre K., Gupta R. 2008.The role of conservation agriculture in sustainable agriculture. Philos. *Trans. R. Soc. B., 363: 543-555.*

Ibeawuchi II. 2007. Landrace legumes: Synopsis of the culture, importance, potentials and roles in agricultural production systems. Journal of Biological Science 7 (3): 464-474.

IFPRI (International Food Policy Research Institute), 2010. Maize Value Chain Potential in Ethiopia Pulse export promotion agency).Available at www.ifpri.org/*sites/ default/ files/.../ Ethiopian agsectorwp_pulses.pdf.* Accessed 1 September, 2021

International Board for Plant Genetic Resources (IBPGR), 2005. Lima bean (*Phaseolus lunatus* L.) descriptors AGPG: IBPGR/82/5. pdf. Rome, Italy

Ipsilandis CG, Vafias BN., 2005. Plant density effects on grain yield per plant: Breeding implications. *Asian J. Plant Sci*., 4 (1): 31 – 39.

JARC, 2008. Meteorological data summary Jimma Weather Station. Jimma Agricultural Research Center, Jimma, Ethiopia.

Jibril Temesgen, Taye Kufa, and Zeleke Wondimu. 2015. Effect of Plant Density of Hybrid Maize and Common Bean Varieties on the Productivity of Intercropping System at Jimma, South West Ethiopia. M.Sc. Thesis, Jimma University., Pp.31-51

Kamanga BCG., Waddington SR., Robertson MJ., Giller KE., 2010. Risk analysis of maize-legume crop combinations with smallholder farmers varying in resource endowment in central Malawi. *Exp. Agric*. 46(1):1-21. *http://dx.doi.org/* 10.1017/ S00144797 09 990469.

Kaplan, L., 1965. Archeology and domestication in American Phaseolus (beans). Economic Botany, 19(4):358-368.

Kebede Michael Gezahegne Bogale, Mosisa Worku, et al., 1993. Maize production trends and research in Ethiopia. In: T Benti and JK Ransom (Eds). Proceedings of the first national maize workshop of Ethiopia, 10-12 November 1992 Addis Abeba. CIMMYT. Pp. 4-12.

Kenasa Dereje. 2020. Diversity of Lima Bean (*Phaseolus Lunatus* L.) Landraces, Agro-Ecological Distribution and Its Socio-economic importance In Western Oromia, Msc. Thesis. Jimma, Ethiopia (Un Published).

Kgasago, H., 2006. Effects of planting dates and density on yield and yield components of short and ultra-short growth period maize (*Zea mays L.*). Masters dissertation. University of Pretoria, South Africa. Pp106.

Khan M. Sultana1 N., Akter N., Zaman M. and Islam M. 2018. Intercropping Gardenpea (*Pisium Sativum*) With Maize (*Zea Mays*) At Farmers' Field. Bangladesh J. Agril. Res. 43(4): 691-702

Kheroar S., and Patra C. 2013. Productivity of maize-legume intercropping systems under Rain fed situated situation. *Afri. J. Agric. Res.,* Vol. 9(20), pp. 1610-1617, 5 May, 2014

Kumar, S. 2012. Production potential, soil moisture and temperature as influenced by maize-legume intercropping. Int. J. Sci. Nat. 3, 41–46.

Landon J.R. 1991. Booker tropical soil manual: A hand book for soil survey and agricultural land evaluation in the tropics and sub tropics. (ed). John W. and Sons I., New York, USA.

Layek, J., Das, A., Mitran, T., Nath, C., Meena, R. Yadav, G. and Lal, R 2018. Cereal+legume intercropping: An option for improving productivity and sustaining soil health (pp. 347–385). Singapore: Springer Nature.

Leyila Nasir, Tileye Feyissa and Zemede Asfaw. 2021. Genetic diversity analysis of Lima bean (*Phaseolus lunatus* L.) Landrace from Ethiopia asreveled by ISSR marker, Addis Ababa University; Ethiopia. J. Sci., 44(1):81–90.

Ludlow, M.M. and R.C. Muchow, 1988. Critical evaluations of the possibilities for modifying crop for higher production per unit of precipitation. Pp. 79-212.

Luis, C.G., Mario, D.M., Alma, M.A., Gloria, D.O. and David, B.A., 2012. Lima bean (*Phaseolus lunatus*) protein hydrolysates with ACE-I inhibitory activity. *Food and Nutrition Sciences* 3(4):511-521 doi: 10.4236/fns.2012.34072.

Lulie Belstie, Walelign Worku Sheleme Beyene. 2016. Determinations of Haricot Bean (*Phaseolus vulgaris* L.) Planting Density and Spatial Arrangement for Staggered Intercropping with Maize (*Zea mays* L.) at Wondo Genet, Southern Ethiopia. Acad. Res. J. Agri. Sci. Res. 4(6): 297-320

Mackie, W. 1943. Origin, dispersal, and variability of the Lima bean, *Phaseolus lunatus.* Hilgardia 15(1): 1-29.

Madonni, G.A., Otegui, M.E. & Bonhomme, R., 1998. Grain yield components in maize: II. Post silking growth and kernel weight. *Field Crops Res*. 56, 257-264.

Mahapatra S.c. 2011. Study of Grass-Legume Intercropping Systems in Terms of Competition Indices and Monetary Advantage Index under Acid Lateritic Soil of India. *American Journal of experimental agriculture.1 (1):1-6.*

Makgoga W. M.**,** 2013**.** Influence of lablab (*Lablab purpureus*) and dry bean (*Phaseolus vulgaris*) intercrops with maize *(zea mays l.)* on maize grain yield and soil fertility status. MSc. Thesis University of Limpopo South Africa. 55p.

Mandal M.K., Banerjee M., Banerjee H., Alipatra A., Malik G.C. 2014. Productivity of maize (*Zea Mays)* based intercropping system during Kharif season under red and lateritic tract of west Bengal. The Bioscan, 9(1): 31-35.

Martin, A. P., 1993. Tropical soils and fertilizer use. Intermediate tropical agriculture series. University of Nairibi, Kenya.Pp.1-32.

McCann J., 2001. Maize and Grace: History, Corn, and Africa's New Landscapes, Pp.1- 267. available at. http://www.blackherbals.com/maize_and_grace_jamesmccann.pdf Accessed 12 July, 2022.

Metwally AA, Safina SA, Abdel TI, Abdel ShI, Hefny YA 2018 Productivity of bean varieties under intercropping culture with corn in Egypt. Soybean Research 16(1&2): 63 - 77.

Mid more, D. J., 1993. Agronomic modification of resource use and intercrop production. *Field Crops Res.,* 34: 354–380.

Moradi, H., M. Noori, A. Sobhkhizi, M. Fahramand, and K. Rigi. 2014. Effect of intercropping in agronomy. J. Novel Applied Sci. 3 (3):315-320.

Mucheru – Muna M., Pypers P, Mugendi D., Kung'u J., Mugwe J., Merckx R., Vanlauwe B., 2010. A staggered maize legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. *Field Crops Res.,* 115: 132–1339.

Mulatu K., Bogale G., Tolessa B., Dessalegn Y. and Afeta A., 1992. Maize production trends and research in Ethiopia. In: Tolessa B. and Ransom J.R. (eds.), Proceedings of the First National Maize Workshop in Ethiopia. Addis Ababa, Ethiopia, pp. 26–34.

Natarajan, M. and R.W. Willey, 1980. Sorghum/pigeon pea intercropping and the effect of plant population density. II. Resource use. *Journal of Agricultural Science,* 95: 51-58.

Niringiye S.C., Ssekabembe S.C., Kyamanywa S. 2005. Effect of plant population on yield of maize and climbing beans grown in intercropping system. *African Crop Sci. J.,* 1(1): Pp. 83-93.

Nthabiseng, T.R.; Irvine, K.M. 2015. Moshibudi, P.M. Response of a maize or dry bean intercrop to maize density and dry bean arrangement under rainfed conditions. Int. J. Agron. Agric. Res. ISSN, 6, 18–29.

Ofori F. and Stern W.R. 1987. Cereal/legume intercropping systems. *Advances in Agronomy* 41: 41-90.

Okigbo, B.N., and D.J. Green land, 1976. In "Multiple Cropping" (R.I. Papendick, P.A. Sanchez, and G.B. Triplett, (eds.), Pp. 63-101. Spec. Pub. No.27. American Society of Agronomy, Madison, Wisconsin.

Osagie, A.U. and Eka, O.U.; (eds). 1998. Nutritional quality of plant foods post-harvest research unit, University of Benin. Pp. 34-41.

Oshodi, A. A. and Aletor, V.A. 1993. Functional properties of haemagglutinins (lectins) extracted from some edible varieties of Lima beans (Phaseoluslunatus). International Journal of Food Science and Nutrition 44: 133−136.

Ossom EM, Rhykerd L 2007. Effect of corn (*Zea mays* L.) and grain legume associations on soil mineral nutrient concentration, soil temperature, crop yield, land equivalent ratio and gross income in Swaziland. African Crop Science Proceedings, 8: 225-230.

Pal, M., K.A. Singh and Ahlawat I.P.S. 1985. Cropping systems research: Indices and assessments. Pp. 23-45. Nat. symp. *Indian Soc. Agron*. CSSRI Karnal, 3-5 April.

Pal, U.R., Oseni T.O. and Norman J.C., 2004. Effect of Component Densities on the Productivity of Soybean/Maize and Soybean/Sorghum Intercrop. *J. Agron. Crop S.,* 170: 66-70.

Pal, U.R., T.O. Oseni and J.C. Norman. 1993. Effect of Component Densities on the Productivity of Soybean/Maize and Soybean/Sorghum Intercrop. *J. Agron. Crop S.,* 170: 66-70.

Palaniappan, S.P., 1985. Cropping systems in the tropics, principles and management. Wiley Eastern Limited. Tamil Nadu Agricultural University. India. Pp. 75-80.

Papendick, R.I., Sanchet P.A. and Triplett G.B., 1976. Multiple Cropping. ASA special publication No. 27. In: Vandermeer John (ed.) 1989. The Ecology of Intercropping. 36 (2). Cambridge University Press.

Patra BC, Mandal BK, and Padhi AK., 2000. Production potential of winter maize (*Zea mays*)- based intercropping system. *J. Agric. Sci*. 70(4):203-206.

Patra BC, Mandal BK, Padhi AK.,1999.suitability of maize (*Zea mays*) based intercropping systems. *Indian J. Agric .Sci*. 69 (11):759-762.

Popoola, J., Ojuederie, O., Omonhinmin, C. and Adegbite, A., 2019. Neglected and underutilizedlegume crops: Improvement and future prospects. In *Recent Advances in Grain Crops Research*. IntechOpen.

Purseglove, J. W., 1968. Tropical crops. Dicotyledons 1. London.

Reddy R.S. 2000. Principles of Crop Production. Kalyani Publishers, New Delhi-110002, India.

Renwick, L.L.R.; Kimaro, A.A.; Hafner, J.M.; Rosenstock, T.S.; Gaudin, A.C.M. 2020**.** Maize pigeonpea intercropping outperforms monocultures under drought. Front. Sustain. Food Syst. 4, 253. [CrossRef].

Reza, Z. O., Allahdadi, I., Mazaheri, D., Akbari, G. A., Jahanzad, E., and Mirshekari, M. 2013. Evaluation of quantitative and qualitative traits of forage sorghum and lima bean under different nitrogen fertilizer regimes in additive-replacement series. Journal of Agricultural Science, 4, 223.

Rezaei-Ch. E., Nassab M., Dabbagh A., Shakiba R. M., Ghassemi- Golezani, K., Aharizad S., and. Shekari F., 2011. Intercropping of maize (*Zea mays L.*) and faba bean (*Viciafaba L.*) at different plant population densities. Department of Agronomy and Plant Breeding, Faculty of Agriculture, Tabriz University, Tabriz- Iran. Pp. 1791.

Rezende, G.D.S.P. and Ramalho, M.A.P., 1994. Competitive ability of maize and common Cereal- Legume Intercropping Systems. *Advanced in Agronomy*, 41: 42-52.

Rodriguez, C.; Carlsson, G.; Englund, J.-E.; Flöhr, A.; Pelzer, E.; Jeuffroy, M.-H.; Makowski, D.; Jensen, E.S. 2020. Grain legume-cereal intercropping enhances the use of soil-derived and biologically fixed nitrogen in temperate agroecosystems. A meta-analysis. Eur. J. Agron., 118, 126077. [CrossRef]

Saka JO, Ajibade SR, Adeniyan ON, Olowoyo RB, Ogunbodede BA. 2004. Survey of under-utilized grain legume production system in South-west Agricultural zone of Nigeria. Journal of Agriculture and Food Information 7: 93-108

Santalla M., Rodino A., Casquero P. and Ron A. 2001. Interaction of bush bean intercropped with field and Sweet maize. European Journal of Agriculture, 15:185-196

Sarquis, J.I., Gonzalez, H. & Dunlap, J.R., 1998. Yield response of two cycles of selection from a semi-prolific early maize (*Zea mays L.)* population to plant density, sucrose infusion and pollination control. *Field Crop Res*. 55, 109-116.

SAS Institute. 2012. The SAS System for Windows.Release 9.2. Cary, NC: SAS Institute.

Schneider Kate and Anderson Leigh, 2010. Yield Gap and Productivity Potential in Ethiopian Agriculture: Staple Grains & Pulses. Prepared for the Farmer Productivity Team of the Bill & Melinda Gates Foundation Pp. 1-13.

Sisay T., 2004. Effect of planting pattern and proportion of green gram *(Vigna radiate (L) wilczec*) on productivity of sorghum/green gram intercropping system in Kewet wereda. Amhara Region. MSc. Thesis, Alemaya University. Pp. 33-45.

Siva K., M.V.K., 1993. Growth and Yield of Millet and Cowpea in Rely and Intercrop sytems in the Sahelian Zones in years when the onset of the rainy season is early. *Exper. agric.* 29(4): 417-427.

Smýkal, P., Coyne, C.J., Ambrose, M.J., Maxted, N., Schaefer, H., Blair, M.W., Berger, J., Greene, S.L., Nelson, M.N., Besharat, N. and Vymyslický, T., 2015. Legume crops phylogeny and genetic diversity for science and breeding. *Critical Reviews in Plant Sciences*, 34(1-3**)**:43-104.

Steiner, K.G., 1984. Intercropping in tropical small holders' agriculture with Special Reference to West Africa. Eschborn: GTZ. 217- 304 p.

Szumigalski A.R., Van Acker R.C., 2006. Nitrogen yield and land use efficiency in annual sole crops and intercrops. Agron. J., 98: 1030-1040.

Tamado Tana. 1994. Intercropping of groundnut (*Arachis hypogaea* L.) and sorghum (*Sorghum bicolar* L., Moench) with emphasis on spatial arrangements. M.Sc. Thesis, Alemaya University, Alemaya, Ethiopia. 94p.

Tamiru Hirpha. 2013. Effect of Interceding Date on Growth and Yield of Three Legume Crops Intercropped with Maize (*Zea mays*). J. Biol. Chem. Research. Vol. 30 (2): 652- 673.

Tekalign Tadese 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Thobatsi, T. 2009. Growth and yield response of maize (*Zea mays L.*) and Cowpea (*Vigna unguiculata L.*) in intercropping system. Masters dissertation. University of Pretoria, South Africa. Pp.67.

Tolera Abera, Tamado.Tanaant and Pant M.L., 2005. Grain yield and LER of Maize-climbing Bean Intercropping as Affected by Inorganic, Organic Fertilizers and Population Density in Western Oromia, Ethiopia. *Asian J. of Plant Sci.* 4(5): 458-465.

Tolera Abera 2003. Effects nitrogen, phosphorus farmyard manure and population of climbing bean on the performance of maize (*Zea mays* L.)/ climbing bean (*Phaseolus vulgaris* L.) intercropping system in Alfisols of Bako. MSc Thesis, Alemaya University, Alemaya.1-75 pp.

Tolessa Debele, Tesfa Bogale, Wakene Negassa, Tenaw Workayehu, Minale Liben, Tewodros Mesfin, Beirtukan Mekonen, and Waga Mazengia 2001. A review of fertilizer management research on maize in Ethiopia. In: *Enhancing the contribution of maize to food security in Ethiopia:* (eds. Mandefro Nigussie, Tanner D. and Afriyie S.) Proceedings of the second national maize workshop of Ethiopia. Addis Ababa, Ethiopia: CIMMYT and EARO. PP: 46-54.

Trenbath, B.R., 1974. Biomass productivity of mixtures. *Advances in Agronomy,* 26: 177-210.

Trenbath, B.R., 1982. Proc. Front Res. Agric. Indian Statist. *Advanced in Agronomy*. 41: 41-42.

Tsedeke A, Monica F, Tahirou A, Girma TK, Rodney L, Paswel M, Woinishet A. 2017. Characteristics of maize cultivars in Africa: How modern are they and how many do smallholder farmers grow. Agriculture and Food Security 6:30.

Tsubo M., Mukhala E., Ogindo H. and Walker S. 2003. Productivity of maize-bean intercropping in a semi-arid region of South Africa. *Water SA*, 29:381-388.

Tsubo M., Walker S., Mukhala E., 2001. Comparisons of radiation use efficiency of mono-/inter-cropping systems with different row orientations. *Field Crops Res.,* 71:17- 29.

Tsubo, M., Ogindo, HO & Walker, S., 2004. Yield evaluation of maize-bean intercropping in a Semi-arid region of South Africa. *Afri. Crop Sci.,* 12(4): 351-358.

Turk M. Tawaha M. and El-Shatnawi J. 2003. Response of Lentil (*Lenscul inarismedic*) to plant density, sowing date, phosphorus fertilization and ethephon application in the absence of moisture stress. *J. Agron. Crop Sci.,* 189: 1-6.

Undie U. Uwah D. and Attoe E. 2012. Effect of Intercropping and crop arrangement on yield and productivity of late season maize/soybean mixtures in the humid environment of Southern Nigeria. *J. Agric. Sci., 4(4): 37-50.*

Van der Maesen L.J.G., and Sadikin Somaatmadja. eds., 1989. Plant Resources of South-East Asia (pp. 15-32). Wageningen, the Netherlands: Pudoc.

Vasic G. Kovacevic D., Cvetkovic R., Oljaca S., and Momirovic N., 2000. Effect of plant arrangement pattern and irrigation on efficiency of maize (*Zea mays* L) and bean (*Phaseolus vulgaris* L.) intercropping system. *Journal of Agricultural Science, Cambridge* (2000), 135, 261-270. 2000 *Cambridge University Press.*

Walker, S &Ogindo, HO., 2003. The water budget of rain fed maize and bean intercrop. *Physics and Chemistry of the Earth*. 28: 919-926.

Walkley A. and Black I.A. 1934. An examination of the Degtjareff method for determining soil organic method, and a proposed modification of the chromic acid titration method. *Soil Sci. 34: 29-38*

Willey R., Natarajan M., Reddy M., Rao M., Nambiar P., kanniayan J. and Bhatnagar V. 1983. Intercropping studies with annual crops. International crops Research Institute for the semi-arid tropics, India.

Willey R., and Osiru D. 1972. Studies on mixtures of maize and beans (*Phaseolus vulgaris* L.) with particular preference to plant population. *J. Agric. Sci.,* 79: 519-529.

Willey R., 1979. Intercropping – its importance and research needs. Part 1. Competition and yield advantages. *Field Crops Abstracts* 32, 1–10.

Woolley, J. and Smith, M., 1992. Detrmination of maize plant types suitable for present and possible relay system in Central America. CIAT Abstr. *On Field Beans*, xvii (3):9-15.

Woolley J. and Davis, J. 1991.The agronomy of intercropping with beans. In: common beans: Research for crop improvement. CABI/CIAT publication. Pp.7-9

Wortman C. 2006. Common bean (*Phaseolus vulgaris* L.). In: Brink, M. and Belay, G. (ed). Plant resources of tropical Africa 1. Cereals and pulses. PROTA Foundation, Blackhuys publishers, Leiden, Netherlands/CTA, Wagenigen, Netherlands. Pp. 146-151.

Yadav, R.L., Prasad K. and Wivedi B.S. D, 1998. Cropping systems research. Pp.193- 213. In: R.L. Yadav, P. Singh, and R. Prasad and I.P.S. Ahlawati (eds.). Fifty Years of Agronomic Research in India. *Indian Soci. Agron.,* New Delhi.

Yayeh Bitew 2014. Influence of small cereal intercropping and additive series of seed proportion on the yield and yield component of lupine *(Lupinus Spp.)* in North Western Ethiopia. *Agriculture, Forestry and Fisheries. 3(2):133-141*.

Yesuf Moha. 2003. Effects of planting arrangement and population densities of haricot bean on productivity of sorghum/haricot bean additive mixture. M.Sc. Thesis, Alemaya University.Pp.57.

Yoseph Beyene, Anna-Maria Botha and Alexander A. 2006. Genetic diversity in traditional Ethiopian highland maize accessions assessed by AFLP markers and morphological traits. Biodiversity and Conservation 15:2655–2671

Zardari S., Elahzad S., Zehtab-Salmasi S., Parast M. B. (2013). Study of growth analyze of bean (phaseolus vulgaris) in different intercropping patterns with dill (Anethum graveolens). International Journal of Agriculture and Crop Sciences. Available online at www.ijagcs.com

Zerihun Abebe, Tadesse Birhanu, Shiferaw Taddese. and Kifle Degefa. 2014. Conservation Agriculture: Maize-legume Intensification for Yield, Profitability and Soil Fertility Improvement in Maize Belt Areas of Western Ethiopia. *Intern. J. Plant & Soil Sci., 3(8): 969-985.*

Zerihun Abebe. 2015. Evaluation of climbing beans intercropped with maize varieties at different time of bean planting. OARI-BARC, Batu, Ethiopia Activities Review March.

Zhang G., Yang Z. and Dong S. 2011. Interspecific competitiveness affects the total biomass yield in alfalfa and maize intercropping system. Field Crops Res.

Zhang R., Li Y., Meng L., Wang X., Sang P., et al., 2021**.** Yield and nutrient uptake dissected through complementarity and selection effects in the maize/soybean intercropping. Food Energy Secur, 10, 379–393. [CrossRef].

7. APPENDIXES

Appendix Table 1. Analysis of Variance for Phenology and growth parameters of Maize as influenced by lima bean planting density, at Seka site

Source of Variation	**DF**	**Mean Square**					
		DNPT	**DNPS**	**DNPPm**	**LA**	**LAI**	**PH**
Treatments	3	7.2^{ns}	5.3^{ns}	13.2^{ns}	1546.5^{*}	0.31^{ns}	171.8^{ns}
Rep	3	16.3	14.8	12.7^{ns}	6147.5	0.73	226.1
Error	9	6.23	4.51	5.23^{ns}	385.0	0.13	63.65
Level of significance for treatment		**0.3**	**0.3**	**0.1**	**0.04**	**0.13**	**0.11**

*, **, *** and ns denotes significant at $P \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ probability levels respectively; ns= not significant; DF= degree of Freedom; DNPT, DNPS, DNPPm denotes Date of ninety percent tasseling, silking and physiological maturity respectively, LA=leaf area, LAI= leaf area index, PH= plant height

Appendix Table 2. Analysis of Variance for Phenology and growth parameters of Maize as influenced by lima bean planting density, at Dimtu site

Source of Variation		**Mean Square**					
	DF	**DNPT**	**DNPS**	**DNPPm**	**LA**	**LAI**	**PH**
Treatments	3	2.75^{ns}	0.63^{ns}	6.8*	5526.6**	0.41^{**}	102.7^{ns}
Rep	2	18.08	13.5	9.2	7186.8	0.05	244.0
Error	6	7.08	3.80	1.47	396.34	0.02	72.0
Level of significance for treatment		**0.76**	**0.73**	**0.05**	**0.0041**	**0.0015**	**0.3245**

*, **, *** and ns denotes significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom; DNPT, DNPS, DNPPm denotes Date of ninety percent tasseling, silking and physiological maturity respectively, LA=leaf area, LAI= leaf area index, PH= plant height

Appendix Table 3. Analysis of Variance for yield and yield components of maize at Seka site

Source of Variation	DF	Mean Square							
		NCPP	NRPC	CL	NKPR	HSW	MGY	AGB	HI
Treatments	3	0.16**	1.02ns	21.6	241.6***	59.08**	1.6***	152.3***	230.0***
Rep	3	0.02	0.13	0.86	10.5	13.5	0.6	3.1	1.25
Error	9	0.009	0.34	2.18	9.5	6.67	0.075	7.25	6.69
Level of significance for treatment		0.0003	0.09		0.0001	0.0048	0.0002	0.0002	<.0001

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom; NCPP= № of cob per plant, NRPC=№ of row per cob, CL=cob length, NKPR=№ of kernels per row, HSW= hundred seed weight, MGY=maize grain yield, AGB=above ground biomass, HI= harvest index.

Appendix Table 4. Analysis of Variance for yield and yield components of maize at Dimtu site

Source of Variation	DF	Mean Square							
		NCPP	**CL**	**NRPC**	**NKPR**	**HSW**	**MGY**	**AGB**	**HI**
Treatments	3	0.05**	10.55	1.93**	166.46 ns	62.58*	0.56*	32.47*	80.3**
Rep	2	0.01	4.54	0.04	8.12	2.68	1.31	1.36	43.3
Error	6	0.002	0.69	0.29	0.67	9.11	0.060	4.73	9.806
Level of significance for treatment		**0.0008**	**0.005**	**0.02**	**<.0001**	**0.0228**	**0.01**	**0.02**	**0.01**

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom; NCPP= № of cob per plant, NRPC=№ of row per cob, CL=cob length, NKPR=№ of kernels per row, HSW= hundred seed weight, MGY=maize grain yield, AGB=above ground biomass, HI= harvest index.

Appendix Table 5. Analysis of Variance for Yield and Yield components of Lima bean, at Seka site

Source of Variation	DF	Mean Square				
		NPPPt	NSPP	PL	HSW	LBGY
Treatments	3	100.36***	0.40**	15.10***	336.1***	55.21**
Rep	3	39.60	0.09	0.66	72.1	6.11
Error	9	4.54	0.05	0.59	32.53	5.10
Level of significance for treatment		**0.0002**	**0.006**	**0.0001**	**0.0028**	**0.002**

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom, NPPPt=Number of pods per plant, NSPP= Number of pods per pod, PL= pod length, LBGY lima bean grain yield

Appendix Table 6. Analysis of Variance for Yield and Yield components of Lima bean, at Dimtu site

Source of Variation	DF	Mean Square				
		NPPPt	NSPP	PL	HSW	LBGY
Treatments	3	180.5***	1.65***	12.94*	241.7*	121.55**
Rep	2	13.3	0.03	0.57	56.4	7.86
Error	6	7.72	0.05	1.91	29.59	10.56
Level of significance for treatment		**0.001**	**0.0003**	**0.02**	**0.02**	**0.0067**

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom, NPPPt=Number of pods per plant, NSPP= Number of pods per pod, PL= pod length, LBGY lima bean grain yield

Appendix Table 7. Analysis of Variance on evaluation of productivity of maize-Lima bean intercropping system, at Seka site

Source of Variation	DF	Mean Square				
		PLER		TLER	MEY	LBEY
		Maize	Lima bean			
Treatments	3	0.04**	0.12**	0.32 ***	1.09**	0.58**
Rep	3	0.0006	0.01	0.03	0.62	0.25
Error	9	0.003	0.011	0.01	0.07	0.04
Level of significance for treatment		**0.001**	**0.002**	**<.0001**	**0.004**	**0.006**

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom, **PLER** and TLER **=** partial land equivalent ratio resp., MEY and LBEY= maize and lima bean equivalent yield resp.

Appendix Table 8. Analysis of Variance on evaluation of productivity of maize-Lima bean intercropping system, at Dimtu site

Source of Variation	DF	Mean Square				
		PLER		**TLER**	**MEY**	**LBEY**
		Maize	Lima bean			
Treatments	3	0.02^{**}	0.16^{**}	0.23^{**}	1.13^{**}	1121.02^{ns}
Rep	2	0.01	0.005	0.02	0.75	2.67
Error	6	0.002	0.015	0.012	0.06	164.4
Level of significance for treatment		0.004	0.007	0.001	0.01	0.0515

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom **PLER** and TLER **=** partial land equivalent ratio resp., MEY and LBEY= maize and lima bean equivalent yield resp.

Appendix Table 9. Analysis of variance for selected soil properties under Maize-Lima bean intercropping at Seka site during 2022/23 cropping season

Source of Variation	DF	Mean Square			
		Ph	Total N (%)	OC (%)	Av.P (Mg kg^{-1})
Treatments	4	0.03271250	0.00086250	0.01195570	0.54315750
Rep	3	0.01949333	0.00067333	0.00171227	1.77804500
Error	12	0.01262250	0.00055250	0.00788743	1.76220750
Level of significance for treatment at 5%		0.09	0.25	0.26	0.87

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom, pH= power of hydrogen, OC= organic carbon, Av.P= available phosphorous.

Appendix Table 10. Analysis of variance for selected soil properties under Maize-Lima bean intercropping at Dimtu site during 2022/23 cropping season

Source of Variation	Mean Square				
	DF	pH	Total N (%)	OC (%)	Av.P (Mg kg^{-1})
Treatments	4	0.05491667	0.00030667	0.18239333	0.54315750
Rep	2	0.10722667	0.00320667	0.42938000	1.77804500
Error	8	0.07352667	0.00053167	0.08801333	1.76220750
Level of significance for treatment at 5%		0.06	0.07	0.2	**0.02**

*, **, *** and ns significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant; DF= degree of Freedom, pH= power of hydrogen, OC= organic carbon, Av.P= available phosphorous.

8. FIGURE OF APPENDIX

Figure of Appendix 1 Agreement to work together at Seka and Dimtu site

Figure of Appendix 2 Land preparation, and planting operatipon at both site

Figure of Photo Appendix 3 Thinning, intercropping and management operation

Figure of Appendix 4 On-field data collection

Figure of Appendix 5 Sample preparation and data recording after sampling

Figure of Appendix 6 Data recording and soil sampling for analysis after harvesting