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EFFECT OF VARIETY AND PLANTING TIME OF HARICOT BEAN (Phaseolus vulgaris L.) IN MAIZE-HARICOT BAEN INTERCROPPING ON THE YIELD AND YIELD COMPONENTS OF THE COMPONENT CROPS IN YILMANA DENSA DISTRICT, NORTH WESTERN ETHIOPIA

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DEPARTMENT OF PLANT SCIENCE

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M.Sc. Thesis Report

By

Dawit Kassaw Tebabal

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

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Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

As a member of the board of examiner of the Master of Science (M.Sc.) thesis open defence examination, we have read and evaluated the thesis prepared by Mr. Dawit Kassaw Tebabal Entitled "**Effect of variety and planting time of haricot bean** (*Phaseolus vulgaris* L.) **in maize-haricot bean intercropping on the yield and yield components of the component crops in Yilmana Densa district, north western Ethiopia**". We here by certify that, the thesis is accepted for fulfilling the requirements for the award of the Degree of Master of Science in Agronomy.

Board of examiners:

Name of external examiners:

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Name ---Signature -------------------- Date --------------------

Name of chairperson:

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DECLARATION

This is to certify that this thesis entitled. "**Effect of variety and planting time of haricot bean** (*Phaseolus vulgaris* L.) **in maize-haricot bean intercropping on the yield and yield components of the component crops in Yilmana Densa district, north western Ethiopia**". Submitted in the partial fulfilment of the requirements for the award of degree of Master of Science in "Agronomy" to the graduate program of college of Agriculture and environmental science in Bahir Dar University by Mr. Dawit Kassaw Tebabal (ID. No. BDU1207284PR) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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LIST OF ABBREVIATIONS AND ACRONYMS

ATER	Area Time Land Equivalent Ratio
A.s.l	Above Sea Level
ANOVA	Analyses of Variances
BH	Bako Hybrid
CIAT	International Centre for Tropical Agriculture
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CSA	Central Statics Agency
CV	Coefficient of Variation
DAP	Di Ammonium Phosphate
EPP	Ethiopian Pulse Production Agency
FAO	Food and Agriculture Organization
GB	Gross Benefit
GLM	General Linear Model
Ha	Hectare
LER	Land Equivalent Ratio
LSD	Least Significant Difference
MAI	Monetary Advantage Index
MRR	Marginal Rate of Return
MT	Metric Tone
NB	Net Benefits
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SNNPE	South Nation Nationalities and Peoples of Ethiopia
TVC	Total Variable Cost
UREA	Di Amide of Carbonic Acid

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ABSTRACT

The ever-increasing human population together with shortage of arable land is the current developmental challenge for developing countries including Ethiopia. So that, intercropping becoming an alternative agronomic practice enabling efficient utilization of resource in special and temporal arrangements that ensures increasing agricultural production per unit area. The experiment was conducted at Adet Zuria within Yilmana Densa district in the West-Gojjam Administrative Zone of Amhara Region, Northwest Ethiopia for the purpose of evaluation of effect of varieties and time of intercropping on growth, yield and yield components of component crops. The experiment was laid out in randomize complete block design in a factorial combination of two varieties of maize (BH 546 AND BH 661), two haricot bean varieties (Batu and Lehode), three times of plantings of haricot bean (simultaneous, two weeks later and four weeks later after maize sowing) and four sole cropping treatments in three replications. The data from phenological, growth and yield parameters of component crops were analysed by using SAS software procedures 9.4 version. The analysis of variance revealed that number of pods per plant, number of seed per pod and grain yield was significantly affected by (both varieties of the component crops) and time of sowing in which variety Batu simultaneously intercropped with BH 546 gave greater values. With regard to maize components, delay planting of intercropped haricot bean affects leaf number per plant and cob number; as planting was delayed by four weeks leaf number was increased by (0.99) from 14.90-15.89, similarly cob numbers were showed increments from 1.50-1.69 as sowing time delayed by 30 days. Grain yield was also influenced by the main effect of varieties of maize and the interaction effect of haricot bean varieties with time of sowing where by variety BH 661 and haricot bean variety Batu intercropped four weeks after maize sowing recorded higher values 7817.7 kg/ha and 7922.6 kg/ha, respectively. On the other hand, intercropping also significantly affects most of component crops parameters where the higher values were recorded in sole cropped treatments. Interms of land use efficiency results, BH 661 simultaneously intercropped with variety Batu recorded the higher LER (1.61) and ATER (1.27) values. Generally, even though it is impossible to deliver valuable recommendation in one-year experiment at a single experimental site, haricot bean variety Batu simultaneously intercropped with BH 661 was the ideal varietal combination with right time of sowing observed in the study area.

Key words: *Cropping system, Haricot bean, Intercropping, Maize and Time of sowing*

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Chapter 1. INTRODUCTION

1.1 Background and Justification

Maize (*Zea mays* L.) is categorized in grass family, Poaceae. It was originated in Central America and was come to Ethiopia during the 1600s to 1700s (Schnable *et al*., 2009). Maize is grown throughout the world, although there are large differences in yields. The Food and Agriculture Organization (FAO) of the United Nations indices of agricultural production include commodities that are considered edible and contain nutrients, and show the relative level of the aggregate volume of agricultural production for each year in comparison with the base period 1999–2001. It is estimated that in 2012, the total world production of maize was 875, 226, 630 tons with the United States, China and Brazil harvesting 31 %, 24 %, and 8 % of the total production of maize, respectively (FAO, 2012).

In Ethiopia maize is the one among most important cereal crops cultivated in the country. From the total area of cereal crop production in 2019/2020 growing season maize covers 23.48% with the production of 102.02 million quintals (CSA, 2020). The total annual production and productivity is greater than all other cereals, even though it is exceeded by tef (*Eragrostis tef*) in area coverage (CSA, 2020). Its productivity is 41.68 quintal/ha in 2019/20 Meher season on farmers' field (CSA, 2020). Approximately 88 % of maize produced in Ethiopia is used as food, both in green cobs and grain (Tsedeke Abate *et al*., 2015). Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socioeconomic conditions typically under rain-fed production. The maize agro-ecologies in Ethiopia can be broadly divided into six major categories (MOA 2005). More than 9 million households, more than for any other crop, grow maize in Ethiopia (CSA, 2011–13 data). The annual rate of growth for the number of households cultivating maize grew at 3.5 % each year between 2004 and 2013, compared to 3.0 % for sorghum, 3.1 % for teff, 2.1 % for wheat, and 1.8 % for barley. At present, as a sub-Saharan country, Ethiopia has the fifth largest area devoted to maize but is second, only to South Africa, in yield and third, after South Africa and Nigeria, in production.

Haricot bean (*Phaseolus vulgaris* L.) categorized in to order Rosales, family Leguminosae subfamily Papilionideae and tribe Phaseolinae (CIAT, 1986). Haricot bean was originated in Tropical America (Mexico, Guatemala, and Peru), even though there are also evidences for its multiple domestication within Central America (Kay, 1979). It is most believed to be introduced to Ethiopia by the Portuguese in the 16^{th} century (Wortman, 1997). Haricot bean is the third most important legume crop next to faba bean and field peas. Major haricot bean producing regions are Central, Eastern, and Southern parts of the country (CSA, 2020). Its productivity is 17.39 and 18 quintal/ha for white and red haricot beans, respectively in 2019/2020 Meher season (CSA, 2020) in a farmer field. In Ethiopia, haricot bean is grown principally under smallholder producers as an imperative food crop and source of cash. It is one of the fast-growing legume crops that provide an essential part of the daily diet and source of foreign currencies for most Ethiopians (Girma Abebe, 2009).

Hobbs *et al*. 2008 stated that over the years, food production for increasingly growing population from a limited farm size is a prime developmental challenge. So that, the commonest practice to increase agricultural production is to increase yield per unit area of land. Agriculture in the next decade must have to produce more food from limited area of land through more efficient use of natural resources with minimal impact on the natural environment in order to achieve the growing population demands. High population pressure and shortage of arable land is a prime developmental challenge in many developing nations to fulfil their food and nutritional requirements. In addition, low soil fertility, limited availability of resources to farmers, nutrient mining and drought are also the main causes for low agricultural productivity in those nations (Mc Cann., 2005).

Intercropping, is an intensive agronomic practice of cultivating two or more crops in the same space at the same time that can balance efficiently crop demands to the available growth resources and labour. The importance of intercropping is that the production of greater yield on a given piece of land by enabling the crop more efficient use of the available growth resources using a mixture of crops of different root-structure, canopy width, plant height and nutrient demands based on the complementary utilization of growth resources by the component crops (Lithourgidis *et al.,* 2011). Legume-cereal intercropping especially maize-bean intercropping is a common practice throughout developing world and can be the ideal ones for sustainable production and food security to resource poor farmers (Tsedeke Abate *et al.,* 2015).

In achieving successful intercropping system; suitable crops and time of sowing (Dwivedi *et al*., 2015), maturity of the crop, and plant density (Hailu Gebru, 2015) need to be considered before and during planting. Many researchers have stressed the need of identification of suitable genotypes for intercropping that best cultivar for mono cropping might not be most suitable for multiple cropping due to change in microclimate within crop mixture (Muoneke *et al*., 2012). Selection of appropriate varieties and time of their establishment are the necessary management options in improving the efficiency of this system. Aiming on increasing the yields of intercrop components crops through minimizing competition effects, selection of compatible varieties and timing of intercropping based on growth characteristics and requirements of the component species in question are key agronomic considerations in intercropping (Banik *et al.,* 2000).

Planting density, varietal selection, understanding the physiology of the species to be grown together, their growth habits, canopy and root architecture and water and nutrient use are important things to be considered in intercropping (Vandermeer, 1989). These factors influence the interaction between the component crops of intercropping and so affect their use of growth resources and determine the success of intercropping compared with sole cropping systems. The current experiment was conducted to evaluate the effect of time of intercropping of haricot bean varieties and maize varieties on growth and yield of component crops in the study area.

1.2 Statement of the Problem

Based on the study of Tsedeke Abate *et al*. (2015) varietal selection, understanding the physiology of the cultivars to be grown together, their growth characters, canopy and root appearance, and water and nutrient use are the most important factors to be considered in intercropping system. The growth character of component crops of intercropping can affect their use of environmental resources and determines the success of intercropping compared with sole cropping systems.

As to the choice of the better planting time of one crop in relation to another in intercropping is the one among the problems related to the multiple crops in developing countries. It is a critical factor towards a stable competitive relationship in intercropping directly affecting the yield of each culture, the best use of the area plus soil conservation (Beltrao *et al*., 2010; Egbe, 2010).

Competition among mixtures is considered to be the major aspect affecting yield as compared with solitary cropping of cereals. Species or variety selections, seeding ratios, special and temporal arrangements and competition capability within row or mixtures intercropping may affect the growth of the species used in intercropping systems (Dhima *et al.,* 2007). Identification of compatible varieties of maize and beans (for both bush and climbing types) at appropriate time of planting is very essential to get optimum yield of the companion crops without affecting the yield of the main crops.

However, most farmers in study area intercrop maize with faba bean and few intercrop maize with haricot bean and yet they have followed traditional way of mixing the component crops without the consideration of research findings. Furthermore, they don't have evidence-based information indicating which varieties of haricot bean will best match with which variety of maize in the intercropping system in the area. Hence, this research proposal was initiated to evaluate the effect of intercropping of haricot bean varieties and time of intercropping of haricot bean with maize on growth, yield and yield components of component crops in the study area.

1.3 Objectives

1.3.1 General objective

- ✓ The general objective of the study was to boost the productivity of component crops in maize-haricot bean intercropping system.

1.3.2 Specific objectives

- ✓ To investigate compatible varieties of maize and haricot bean in an intercropping of the component crops.
- ✓ To determine appropriate time of intercropping of haricot bean and maize varieties for better yield.
- ✓ To select the best maize-haricot bean intercropping combinations with high land use efficiency.
- ✓ To examine comparison of sole and intercropping treatments.

Chapter 2. LITRATURE REVIEW

2.1 Origin and Importance of Maize and Haricot bean

Maize (*Zea mays* L.) belongs to the tribe Maydae, Poaceae family and was originated in Mexico and Central America. The crop consists of somatic chromosome number of 20, a genome size of 2.3 giga base and more than 32,000 genes. Maize grows well in different agro-ecologies and is unparalleled to any other crop due to its ability to adapt in diverse environments (Schnable *et al*., 2009). Based on the description of Oxford English Dictionary (2015) the term 'maize' seems to be derived from the word 'mahiz' of Taino language of the Caribbean islands, which became 'maiz' in Spanish. According to this common name, Linnaeus incorporates the name as species in the botanical classification of Zea.

Based on the study of FAO (2019), in Ethiopia about 9.64 million metric tons of maize is produced every year, the highest among major staple cereals. Maize becomes a crop of world-wide importance because of its multiple end uses as a human food and livestock feed and serves as an important component for varied industrial products. Besides, maize is used as a model organism for biological research worldwide. Haffangel (1961) stated that maize was introduced in Ethiopia slightly later, in the late 17th century and was mainly grown as a subsistence crop in the mid altitudes (1500– 2000 m above sea level) in southern, south-central, and south western regions of the country. The rate of growth for area weakened following the great drought of 1974, and while there was enlargement in the 1980s, the average annual yield was variable and rarely exceeded 1.5 MT/ha. Maize production and its status in determining food security in the country received a great attention in the mid-1980s, particularly spurred by the 1984 devastating drought and the famine that followed.

The better wide adaptability of the crop and its higher potential to produce more calories and food per unit area of land cultivated than all major cereals grown in Ethiopia were important situations in considering maize as part of the national food security strategy, including its inclusion under the government-led intensive agricultural extension program. The major maize production regions of the country are Oromia, Amhara and SNNPE with total area of production 1,390,841.48 hectares, 534,007.80 hectares and 356,365.90 hectares respectively (CSA, 2020).

Based on the study of Bekele Shiferaw *et al.* (2011) a major percentage of maize produced worldwide is used for animal consumption though it serves as an energetic source of proteins and calories to billions of people in developing countries, principally in Africa, Mesoamerica and Asia. Moreover, it is a source of essential vitamins and minerals to the human body. Furthermore, with rice and wheat, maize provides at least 30 % of the food calories to more than 4.5 billion people in 94 underdeveloped countries. Bekele Shiferaw *et al.* (2011) notifies that maize provides over 20 % of total calories in human diets in 21 countries and over 30 % in 12 countries that constitutes a total of more than 310 million people.

Haricot bean (*Phaseolus vulgaris* L.) is categorized in order Rosales, family Leguminosae subfamily Papilionideae and tribe Phaseolinae (CIAT, 1986). Kay (1979) notified that haricot bean was originated in Tropical America (Mexico, Guatemala, and Peru), but there are also evidences for its multiple domestication within Central America. The crop is currently widely distributed throughout the world and consequently, it is grown in all continents with the exception of Antarctica (Singh, 1999). In Ethiopia, it is mostly believed to be introduced by the Portuguese in the 16^{th} century (Wortman, 1997). It is well adapted to an area that obtains an annual average rainfall ranging from 500–1500 mm with optimum temperature range of 16°C–24 °C, and a frost-free period of 105 to 120 days. In addition, it performs good on deep, friable and well aerated soil types with optimum pH range of 6.0 to 6.8 (Kay, 1979). The major haricot bean producing areas are Central, Eastern, and Southern parts of the country and in central Ethiopia. Among those Oromia, south nations' nationalities and peoples of Ethiopia and Amhara covers with area of 112245.48 hectares, 82251.68 hectares and 65679.5 hectares, respectively (CSA, 2020).

With the concern of economic importance of haricot bean, it is used as source of foreign currency, food crop, means of engagement, source of cash and plays great role in the farming system (CSA, 2005). Based on the study of EPPA (2004) in the year 2000, 2001 and 2002 Ethiopia exported 23994.4, 32932.7 and 42127.0 tones and earning 8.2, 9.98 and 13.2 million united states dollar, respectively. Legese Dadi *et al*. (2006) shows the country's export potential of haricot beans have increased over the last few years, from 58,126 MTs in 2005 to 78,271 MTs in 2007 and Ethiopia receives 63 million dollars from haricot bean market in 2005.

2.2 Agro Ecological Requirements of Maize and Haricot bean

Maize crop can grow under diverse conditions from sea level to about 3000 m altitude throughout the year in many parts of the world. Maize crop requires 21 - 32°C temperature for proper germination and growth with optimum moisture availability. For instance, 50–75 cm of well distributed rain is ideal for proper growth. During flowering, extreme temperature and low humidity damages the foliage, dries the pollens interferes with pollination and decreased grain formation. Maize is highly sensitive to water stagnation especially during early period of growth (Catherine Ragasa *et al*., 2013 and Singh *et al*., 2017).

Haricot bean is adapted to a wide range of climatic conditions starting from sea level to nearly 3000 meters above sea level (m.a.s.l.) depending on variety. However, it does not grow well below 600 meters due to poor pod set caused by extreme temperature (Dev and Gupta., 1997). It grows best in warm climate at temperature range of 18°C to 24°C (Girma Abebe, 2009). Fikru Mekonnen (2007) suggested that common bean grows well between 1400 and 2000 m.a.s.l. In addition, Kay (1979) reported that the crop is well adapted to areas that receive an annual average rainfall ranging from 500-1500 mm with optimum temperature range of 16°C-24°C, and a frost-free time of 105 to 120 days for maturity. Moreover, haricot bean grows well on deep, friable and porous soil types with optimum pH range of 6.0 to 6.8. The major common bean producing areas of Ethiopia are central, eastern and southern parts of the country (CSA, 2020).

2.3 History of Intercropping

Historically agriculture practiced through the centuries all over the world, has always use different patterns of intercropping. In most cases, a number of crops have been grown in association with one another for many years and crop mixtures probably represent some of the first farming systems practiced (Plucknett and Smith, 1986). Based on the study of Papanastasis *et al*. (2004) Theophrastus, the famous early Greek philosophers and natural scientists, describes that wheat, barley, and certain pulses could be planted at various times during the growing season often integrated with vines showing knowledge of the use of intercropping.

Now a day, intercropping is practiced in many tropical regions of the world particularly by small-scale traditional farmers (Altieri, 1991). The previous mixture cropping systems are estimated to account as much as 15-20 % of the world's food supply (Altieri, 1999). Farmers of Latin America grow 70-90 % of their beans with maize, potatoes, and other crops whereas; maize is intercropped on 60 % of the maize-growing areas of the region (Francis, 1986). Another numerical evaluation indicated that 89 % of cowpeas in Africa are intercropped, 90 % of beans in Colombia are intercropped, and the total percentage of cropped land actually applied to intercropping ranges from a low 17 % for India to a high percentage (94 %) in Malawi (Vandermeer, 1989).

In the tropical regions, intercropping is typically related with food grain production whereas; in the temperate regions it is getting much attention as a means of efficient forage production (Anil *et al*., 1998; Lithourgidis *et al*., 2006). In small-scale farmers, who often do not have readily access to markets and grow enough food only to sustain themselves and their families, recognize that intercropping is one good way of ensuring their livelihood. Intercropping is a common practice in many areas of Africa as a part of traditional farming systems commonly applied in the area due to diminishing land sizes and food security needs. Intercropping is commonly practiced on small farms with limited production capacity because of shortage of capital to obtain inputs. Implementation of an intercropping system can differ greatly with soil conditions, local climate, economic situation, and preferences of the local community (Dakora, 1996).

Several crop species have been identified as appropriate or unfitting for intercropping. Local varieties which have been certain over the years for this purpose are used for intercropping.

However, in the automated agricultural sector of Europe, North America and some parts of Asia, intercropping is far less prevalent. Although agricultural research formerly focused on sole cropping and ignored the potential of intercropping, there has been a gradual appreciation of the value of this kind of cropping system (Zhang *et al*., 2016).

Apart from its multiple importances, the agricultural intensification in terms of plant breeding, mechanization, fertilizer and pesticide use experienced during the last 50 years has led to elimination of intercropping from many farming systems. However, intercropping has been confirmed to produce higher and steadier yields in a wide range of crop combinations, while the system is characterized by minimal use of inputs such as nourishments and pesticides, stressing the production of healthy, harmless and high-quality food in the context of environmentally comprehensive production. In organic agriculture, intercropping is considered as effective way of self-regulation and resilience of the organic agro-ecosystems to meet environmental perturbations in the organic culture practice (Lammerts van Bueren *et al*., 2002).

2.4 Intercropping Benefits over Sole Cropping

2.4.1 Efficient resource utilization and yield advantages

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 (Hauggaard-Nielsen *et al*., 2001b; Andersen *et al*., 2007; Launay *et al*., 2009 and Mucheru-Muna *et al*., 2010). According to the study of Tsubo *et al*. (2001) yield advantage was prevalent 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 which exploit the variation of the mixed crops in characteristics such as rates of canopy development, final canopy structure, photosynthetic adaptation of canopies to irradiance conditions and rooting depth.

Based on the study of Waddington *et al*. (2007) continuously intercropped cowpea can help to maintain maize yield to some extent when maize is grown without mineral fertilizer on sandy soils in sub-humid zones of Zimbabwe. According to the study of Ghanbari *et al*. (2010) intercropping maize with cowpea has been reported to maximize light interception in the intercrops, reduce water evaporation and improve conservation of the soil moisture compared with maize alone.

According to the study of Midmore (1993) and Morris and Garrity (1993) in ecological terms, resource complementarity minimizes the niche overlap and the competition between crop species and enables crops to capture a greater range and quantity of resources than the mono crops. Improved resource use that ensures in most cases a significant yield advantage increases the uptake of other nutrients such as P, K and micronutrients, and provides better rooting ability and better ground cover as well as higher water use efficiency.

2.4.2 Insurance against crop failure

Based on the study of Ejigu Ejara *et al*. (2017) on the determination of appropriate maize haricot bean arrangement in moisture stress areas indicated that the maize-haricot bean intercropping was very important for small scale farmers in the moisture stress area of Borana lowland because when the rainfall shortage was occurred there was a chance to get yield at least from the haricot bean and to minimize the risk of crop failures happened to small scale farmers.

Different crops have different periods and patterns of growth. If one of the crops fails because of adverse conditions, such as drought, disease or attack by pests the other crop may not respond in the same way to the stress and may give some yield. This will help improve food security in the household (Frederick *et al*, 2016). According to the study of Rao and Willey, (1980) data from 94 experiments on mixed cropping sorghum/pigeon pea showed that for a particular 'disaster' level quoted, sole pigeon pea crop would fail one year in five, sole sorghum crop would fail one year in eight, but intercropping would fail only one year in thirty-six. The stability under intercropping can be attributed to the maintenance of diversity that is lost under mono cropping. From this point of view, based on the study of Clawson (1985) intercropping provides high insurance against crop failure, especially in areas subject to extreme weather conditions such as frost, drought, flood and overall provides greater financial strength for farmers.

2.4.3 Soil conservation

A study conducted out by Pedro *et al*. (2014) on soil loss by water erosion in areas under maize and jack beans intercropped and monocultures illustrates that, intercropping was highly beneficial directly reducing soil losses and considering the crops used jack beans emerged as adequate soil protection, probably due to its initial fast growth when compared to maize. Its lower height with alternate leaves can better prevent soil surface against raindrop impact and thus reduce runoff. Intercropping of maize and jack beans presented a higher soil cover index and consequently, lower crop development factor when compared with single cultivation of maize and jack beans, which confirms the benefits of intercropping on soil protection.

Kariaga (2004) indicated that the low production of runoff and soil loss where maize was intercropped with either beans or cow-peas or both demonstrate the importance of dense ground cover in reducing soil and water losses. El-Swaify *et al*. (1988) also states that deep roots penetrate far into the soil breaking up hardpans and use moisture and nutrients from deeper down in to the soil. Shallow roots adheres the soil at the surface and thereby enable to reduce erosion. Moreover, Frederick (2016) also notified that shallow roots help to aerate the soil. Intercropping results in better soil cover. This has advantages of reduced erosion and nutrient leaching, and improved soil structure and soil microbial activity.

2.4.4 Improvement of soil fertility

Fustec *et al*. (2010) states that, because inorganic fertilizers have contributed to environmental damage such as nitrate pollution, legumes grown in intercropping are regarded as an alternative and sustainable way of introducing N into lower input agro ecosystems. In addition, Fujita *et al*. (1992) explained that legumes enrich soil by fixing the atmospheric nitrogen changing it from an inorganic form to forms that are available for uptake by plants. Biological fixation of atmospheric nitrogen can substitute nitrogen nourishment wholly or in part. When nitrogen fertilizer is inadequate, biological nitrogen fixation is the main source of nitrogen in legume-cereal diverse cropping systems.

Adu-Gyamfi *et al*. (2007) also describes, the use of legumes in mixtures contributes some nitrogen to the cereal component and some residual nitrogen to the following crops. The main pathway of retention of other nutrients is through the return and breakdown of crop residues (Rahman *et al*., 2009). Crop remains characterize a major resource of fertilization for the small-scale farmer and management of the fate of the nutrient released by the decomposition of crop residue is thus a key target for enhancing nutrient use efficiency of cropping systems.

2.4.5 Improvement of forage quality

Combining the growth of cereal forages with other crops capable of increasing the protein content of the portion has excessive nutritional and economic value. Combinations of cereals with legumes are seen as one technique of accomplishing this goal. According to the study of Geren *et al*. (2008) intercropping cereals with legumes and other fodder crops to obtain forage for ensiling offers one method for increasing home-grown protein sources. Moreover, Geren *et al*. (2008) describes, increases in crude protein content by 11-51% were recorded for the various intercrop treatments over corn sole crop. Based on the study of Lithourgidis *et al*. (2007) common vetch intercrops with barley or winter wheat produced higher dry matter than sole common vetch.

Based on the study of Javanmard *et al*. (2009) the crude protein yield, dry matter yield and ash content of maize forage enhanced by intercropping with legumes compared with maize monoculture. Intercropping legumes with maize significantly reduced neutral detergent fibre and acid detergent fibre content, increasing digestibility of the forage. Furthermore, Javanmard *et al*. (2009) notified that intercrops of maize with legumes can substantially increase forage quantity and quality and decrease the requirements for protein supplements compared with maize sole crops.

2.4.6 Lodging resistance to prone crops

Getnet Assefa and Ledin (2001) describes intercropping can provide better lodging resistance for some crops highly susceptible to lodging. Lodging, which is commonly observed in some crops, dominantly can reduce plant growth heavily. Some of the damage is often attributable to subsequent disease infections and mechanical damage, whereas loss of plant height decreases the capacity of solar radiation absorption/interception. The ability of forage crops to remain standing is particularly important because lodged forage crops may not be able to photosynthesize and reduce the movement of assimilates and water, which can result in loss of yield. Moreover, lodged crops may retard harvest operations or may cause harvest loss. Improved stand ability usually ensures in increased harvestable yield, improved crop quality, and increased efficiency of harvest. In addition, based on the study of Rauber *et al*. (2001) lodging resistance for susceptible crops through intercropping; barley with common vetch, corn with climbing bean and wheat with lathyrus is found to reduce lodging of the legume crops. Similarly, Cowell *et al*. (1989) also examined advantageous impacts in mixed stands of lentil (Lens culinaris) and flax (Linum usitatissimum).

2.4.7 Reduction of pest and disease incidence

Girma Hailu *et al*. (2018) showed that intercropping of maize with leguminous crops also provided significant reduction of stem borer and fall armyworm compared to mono-cropped maize, especially in the early growth phases of the maize up to tasselling. In addition, Rao *et al*. (2012) indicated that the diversity created by introducing cluster bean, cowpea, black gram, or groundnut as intercrops in castor resulted in a build-up of natural enemies (Microplitis, coccinellids, and spiders) of the major pests of castor, also resulted in less congenial conditions for insect pests such as A. janata and C. punctiferalis. As a result of the build-up of natural enemies, there was much less pest incidence and damage in castor intercropped with cluster bean, cowpea and groundnut compared to the castor mono crop.

On the other hand, Sekamatte *et al*. (2003) describes soybean and groundnut were more effective in retarding termite attack than common beans, suggesting the necessity to identify compatible legumes for each intercropping situation. Langer *et al*. (2007) shows firstly, the environment of the host plants and secondly, the host plant quality, e.g. morphology and chemical content is altered. Moreover, Afrin *et al*. (2017) concluded that multiple crop species grown in a single land increase biodiversity and encourage natural enemies. Creating mutual interactions misguide insects for host detection, reducing insect pests, lowering pest infestation and lowering external inputs.

Olorunmaiye (2010) also notifies intercrops may show weed control advantages over sole crops in two ways. The minimal weed growth and greater crop yield advantage may be ensured if intercrops are more effective than sole crops in utilizing resources from weeds or reduce the growth of weeds through allelopathy. Intercropping may also provide yield advantages by reducing the growth of weeds below the economic threshold levels observed in sole crops if intercrops use resources that are not in use by weeds or change growth resources into harvestable materials more efficiently than sole crops.

Fewer studies have been done on the effects of intercropping on plant diseases than those on insect pests (Francis 1986). There are evidences that intercropping minimizes disease incidence in some crops when compared with sole crops (Larios and Moreno, 1977; Palti, 1981 and Thresh, 1982). Natarajan *et al*. (1984) showed that intercropping sorghum and pigeon pea reduced fusarium wilt incidence in pigeon pea when compared with sole plantings. In these studies, pigeon pea yields were greater than partial expected yields, but no higher than sole crop yields. The reduction of fusarium wilt was consistent across 14 susceptible genotypes.

2.4.8 Promotion of biodiversity

Intercropping is a sustainable mechanism for introducing more living systems into agro ecosystems and results from intercropping studies indicate that increased crop diversity may increase the number of ecosystem services provided. Altieri (1994) states intercropping of compatible plants promote biodiversity by providing a habitat for a variety of fauna and flora that would not be present in a single crop environment. Stable natural ecosystems are typically diverse, containing numerous different kinds of plant species, arthropods, mammals, birds, insects and microorganisms. Because of this, in stable systems, serious pest outbreaks are rare because natural pest control can automatically bring populations back into balance. Moreover, Thrupp (2002) and Scherr and McNeely (2008) describes on-farm biodiversity can enable to agro ecosystems capable of maintaining their own soil fertility, regulating natural protection against pests, securing natural balance and sustaining productivity. So that crop mixtures which increase farms biodiversity can make crop ecosystems more stable, conducive and thereby reduce pest outbreak occurrences.

2.5. Agronomic Consideration in an Intercropping System

2.5.1. Crop choice

The crop choice is an important consideration concerning the growing situation, crop environment of a locality, suitability of the crop as well as demand and availability of a particular variety (Maitra *et al*. 2020). The appropriate crop mixtures show complementarity among the species cultivated and yield advantage is observed. Similarly, Fan *et al*. (2006), recorded more grain output of faba bean + maize; but the yield of fava bean was less in a faba bean + wheat intercrop combination. These are the examples of the importance of crop choice in yield enhancement while selecting the crop in intercropping, generally, crop morphological and physiological characters are considered. For example, combinations of deep and shallow rooted crops (like finger millet and green gram) or crops with tall and dwarf canopy (like maize + groundnut) are preferred for better utilization of the available resource. Intercropping in maize is very common and legumes are preferably chosen in maize-based intercropping system. In different intercropping studies, it was noted that maize + legume combination registered more yield with greater use of resources (Manasa *et al.,* 2018 and Maitra *et al*., 2020) which are the primary goals of the intercropping system. There are several crop species which may be considered in intercropping, like annuals, perennials and mixture of the both. In alley cropping, a type of agroforestry, perennials are chosen in hedgerows and annual crops are cultivated in alleys.

2.5.2. Crop maturity

Crop maturity is an important factor for the choice of crops in an intercropping system. The crops preferred in intercropping combination should be of a different kind in terms of their grand growth period; otherwise, there may be a chance of inter-species competition for required resources if it coincides. The complementarity among the species is desirable to obtain the benefits of an intercropping system which are reflected as system productivity. Hence, the crops chosen should be of different duration with dissimilarity in the form of growth and morphology as they can exhibit complementarity among themselves. As an example, it may be stated that maize has been considered a suitable cereal species and also treated as a base crop in the intercropping system in association with preferably dissimilar legumes of shorter lifecycle (Maitra *et al*. 2020). Green gram or black gram is of short duration pulse crops when grown as intercrop in association with the base crop of maize, pulses enter into the reproductive stage before maize reaches to the knee-height stage (approximately 6–7 weeks after planting) and thus least competition is observed among the crops. The result of such combination expresses a higher level of mutual benefits in the expression of crop yields of individual species.

2.5.3 Planting density

To obtain optimal yield output it is necessary to maintain proper plant stand. But in replacement series, there will be the reduction of plant population of crop species in comparison to sole crops, whereas in additive series, the base crop gets a similar plant stand and other crops that are accommodated may or may not occupy areas like sole cropping. Furthermore, paired-row geometry of planting of the base crop is beneficial because more space for intercrops is created. Sometimes in replacement series of intercropping system, population density is enhanced compared to the pure stand of individual crops to achieve higher system productivity with greater leaf area index (LAI) (Wang *et al*., 2010). In an intercropping system with base crops like maize, cotton, sugarcane and so on, paired row planting in intercropping is commonly practiced (Manasa *et al*., 2018, Maitra *et al.,* 2001).

2.5.4 Planting time

In intercropping systems, sowing/ planting time of component crops may or may not vary as in relay intercropping system. Intercrops are introduced when the base crop reaches close to its maturity or complete a major period of its growth. The competition among the species is much less in relay intercropping. In south Asian countries, relay cropping of pulses and oilseeds is very common in rainy season rice and by utilizing residual soil moisture and nutrients relay crops yield satisfactorily. When the crops are sown together in intercropping, preferably crops with a different type of growth habit are chosen. For example, in maize-based cropping systems short duration green gram or black gram if sown completely the major part of their growth before maize reaches its peak demand stage. As maize is used as fodder also and maize-legume fodder mixed cropping system is common in different countries. Under this situation, dry matter or biomass production is the ultimate target and competition among crop species does not influence the forage yield. With grain crop maize, legumes generally yield quite reasonably because of wider spacing adopted in maize sowing (Maitra *et al*., 2021).

2.6 Intercropping of Maize with Grain Legumes/Haricot Bean

According to the study of Alom *et al*. (2010) increase grain production per unit area of land has been reported elsewhere by intercropping grain legumes with maize. The modern method of increasing food production includes adoption of modern varieties, practicing of improved cultural techniques, optimum management and following the appropriate cropping systems. Intercropping system is one of the important approaches of cropping systems and emerged as an important tool for increasing crop production. In order to introduce maize and avoid competition from other crops, there is a need for developing technology like intercropping.

Maize-bean intercropping is an important practice to minimize the problem of mono cropping while intensifying to generate diverse food sources and maximize incomes (CIMMYT, 2010). Practicing vertical agriculture in maize based cropping systems is among the basic strategies to boost the production and productivity of the main stable crops in many parts of Ethiopia, where continuous monoculture is the main challenges. Maize-bean intercropping systems are one of the best agronomic practices that ensure high production per unit area while reducing the risk and problem of monocultures. Restoring soil fertility through diversified cropping systems that mimic nature is also considered to be the best options for sustainable agriculture (Scherr and McNeely, 2008).

2.7 Temporal and Varietal Effects on Growth and Yield of Component Crops

2.7.1 Effect of sowing time on growth and yield of maize and haricot bean intercropping

Intercropping is one of the cropping systems experienced for higher crop production returns per unit area. The vital features of intercropping systems are that they exhibit intensification in space and time, struggle between and among the system components for light, water and nutrients and the proper management of these interactions (Hailu Gebresilasie *et al*., 2015). Mburu *et al*. (2003) reported that intercropping in general and delayed planting of legume in maize in particular, significantly and drastically depressed legume biomass yields compared to sole legume yields. Gbaraneh *et al*. (2004) have also reported highest lablab fodder yield obtained when maize and lablab were simultaneously planted, and declined progressively with delayed under sowing of lablab.

On the other hand, Carruthers *et al*. (2000) notified that significant difference in harvest index, number of pods per plant and number of seeds per pod was not observed due to planting time of soybean in maize. Competitive advantage to the main crop in staggered sowing of the intercrops have been reported by different workers, in which earlier sown component showed better growth and yield than simultaneously sown (Gbaraneh *et al*., 2004 and Mousa *et al*., 2007).

Huang *et al*. (2018) showed that intercropping could reduce ear density, thus decreases the yield. In this case, early sowing date could enhance the competitive ability of intercropping maize and improve grain yield as a result of higher grain weight. Earlier maize sowing could be an effective practice for producing more grain in an intercropping system. Plant to plant interactions play a key role in yield production due to changing the yield component formation in the intercropping system. Good timing of planting date is one of the key factors that strongly affect crop production in rain fed agriculture (Ati *et al.,* 2007). Determining the right time to introduce a legume or cereal plant in any intercropping system is highly significant in maximizing the yield components of both plants. Different research findings have suggested many times to intercrop pulses in cereals to ensure maximum yield of both component crops. According to the study of Mongi *et al.* (1976) cowpeas planted three weeks after maize had significantly reduced grain yields and therefore recommends planting cowpeas same time with maize.

The level of competition-brought yield reduction in intercropping is expected to depend on the spatial arrangement and time of planting of the component crops. Spatial arrangement of intercrops is an important management practice that can improve light absorption through more complete ground cover (Heitholt *et al*., 2005). Choice of appropriate date of planting and population density, therefore, seems relevant management options in improving the efficiency of this system. Banik and Sharma (2009) explained there is potential for higher productivity of intercrops when intra-specific competition is less than inter-specific competition for limiting resources. The timing and arrangement of crops in mixture in the traditional farming systems of Adet Zuria, Yilmana Densa Woreda is random and without any sufficient attempt to pattern the crops for effective interception of essential resources with compatible varieties of maize and haricot bean (personal observation). Much of the poor crop yields obtained in ordinary crop production systems of these areas might be attributable in part to improper crop arrangement with its attendant waste of essential environmental resources.

According to the study of Olufajo and Singh (2002) timely planting and selecting more adapted cultivars are potential ways to reduce the negative shading effect of cereal on cowpea. Moreover, Singh and Ajeigbe (2002) and Kamara *et al*. (2011) noted that time of planting affects the extent to which plants of component crops can reach their yield potential. Hailu Gebru (2015) examined for intercropping to be more productive it is recommended that component crops differ greatly in growth duration so that their resource requirement for growth resources occurred at different times. There is an argument that if legumes are intercropped in a timely manner, competition with the companion crop (maize) for light, water and nutrients can be minimized.

2.7.2 Varietal selections and its effect on growth, yield and yield component of crops

Zhang and Li (2003) shows that intercropping has yield advantages governed by the mechanisms of inter specific facilitation (or complementarity) and/or competitive production principles. Due to facilitation and complementarity between species, cereal/cereal and cereal/legume intercropping has been widely practiced and promoted for sustainable agriculture development (Loreau and Hector, 2001; Zhang and Li., 2003).

In Ethiopia, improved maize and common bean varieties have been recommended for wider agro-ecologies over the years. Certainly, compatibility study of varieties in maize/common bean intercropping systems is not well-assessed (Tesfa Bogale *et al*., 2012). Hence, the works have restrictions in detecting varieties of the two crops appropriate for intercropping. Even though maize/common bean intercropping research activities have been done in many places of the country, basic information is not available on morphological characteristics positively influencing performance of component crops useful for use in intercropping. The interest of common bean breeding program has been on market acceptance for canning industries (Ferris and Kaganzi, 2008). In selection of suitable common bean compatible genotypes for a maize/common bean intercrop, Atuahene *et al*. (2004) assessed genotypes of different canopy width and canopy height preferred for better ground cover in intercropping systems. This has been found for haricot bean intercropped with maize (Davis and Woolley, 1993), or cultivar characteristics under an intercropping system (Hauggaard-Nielsen and Jensen 2001), e.g., shade tolerance or shade avoidance of different soybean cultivars in maize/soybean relay intercropping (Wu *et al*., 2017).

Wang *et al*. (2017) examined that in a hybrid maize intercropping system, the difference in grain weight of the different cultivars resulted in contrasting yield potential between intercropping and sole cropping. Yield and yield components depend on genotype, agronomic practices, weather conditions and plant to plant interactions in the intercropping system (Petr *et al*. 1988). Ofori and Stern (1986) notify in an intercropping system, the formation of yield components is closely related to inter specific interactions. Compared with sole cropping maize, the grain yield of the maize in maize/cowpea intercropping was reduced by 18%, mainly because of a lower number of grains per unit area as the main determinant of yield. Whenever crops are produced in an intercropping system, the yield of crop species is mostly reduced as that obtained in sole production system, even though the sum of relative yields is often greater than one (Yu *et al*. 2015 and Martin *et al*. 2018). This yield decrease is due to competitive interactions. Using the same agronomic practices, intercropping greatly reduced maize yield by 0.9–2.8 tons per hectare during two growing seasons in the North China Plain (Huang *et al*. 2018). The choice of cultivars is an easy-to-control practice with little extra costs for smallholder farmers, although many of them do not know how to utilize better cultivars (Zhang *et al*. 2016).

Competition among mixtures is thought to be the major feature affecting yield as associated with solitary cropping of cereals. Species or variety selections, seeding ratios, special and temporal arrangements and competition capability within row or mixtures intercropping may affect the growth of the species used in intercropping systems (Dhima *et al*., 2007). Legumes crops including common bean (bush and climbing types), soybean and groundnut haricot bean and field pea are widely used to intercrop with major cereal crops like maize and sorghum. Identification of compatible varieties of maize and beans (for both bush and climbing types) at appropriate time of planting is very essential to get optimum yield of the companion crops without affecting the yield of the main crops. The best cultivar for mono cropping might not be most suitable for mixed cropping due to change in microclimate within crop mixture (O'Leary and Smith, 2004). According to the study of Adeniyan (2006) maturity time and growth habit of component crops were important determining factors of productivity in maize soybean intercrops. Moreover, Tamado Tana and Eshetu Mulatu (2000) describes the intercrops of maize and bean in 100% of the sole maize population (44,444 plants/ha) and 50% of the sole bean population (125,000 plants/ha) results in high yield. Up on this plant population can be used as a critical practice to manage crop growth, maximize biomass, the time required for canopy closure and yield.

2.8 Competition Indices and their Importance

2.8.1 Land Equivalent Ratio

Land equivalent ratio is described as the proportionate land area required under a pure stand of crop species to yield the same product as obtained under an intercropping at the same management level (Maitra *et al*. 2020). The LER of intercropped plots are estimated for each component crops separately by adding the estimated total of two varieties; the LER of the sole crop is taken as unity (1). The LER denotes the benefits of an intercropping system to utilize the resources as against their pure stands (Mead and Willey, 1980). The LER value greater than unity (1.0) indicates the advantages of the intercropping system (Ofori and Stern, 1987) and less than one (1.0) is considered as a poor performance of the intercrops (Caballero *et al*, 1995).

2.8.2 Area Time Equivalent Ratio

The LER emphasizes on the only land area without considering the time factor for which the crop occupies the field. As time factor is not a part in the LER, researchers needed another expression considering the field occupancy by the crops in an intercropping to correct this constraint of the LER. Hiebsch (1978) developed the concept of Area Time Equivalent Ratio (ATER) in which the duration of crops (starting from seeding to harvest) was considered. Therefore, area time equivalent ratio (ATER) provides more realistic comparison of the yield advantage of intercropping over sole cropping in terms of variation in time taken by the component crops of different intercropping systems (Aasim *et al*., 2008).

2.8.3 Monetary advantage index

The economic feasibility of intercropping over sole cropping is calculated by using the monetary advantage index (MAI). MAI is an important index in determining economic viability of intercropping (Willey, 1979).

2.8.4 Competitive Ratio

In an intercropping system, competitive ratio (CR) denotes the competitive ability of the component species (Willey, 1980). The CR expresses the number of times by which one component crop is more competitive than other (Willey, 1980) and CR actually represents the proportion of individual LERs of the crops considered in intercropping and also takes into account the ratio of the crops sown in a mixed stand. If the value of CR is <1, there is a positive benefit and it means there is limited competition between component crops and therefore they can be grown as intercrops. If the CR value is more than one (CR >1), there is a negative impact. In this condition, the competition between intercrops in mixture is too high, and they are not recommended to grow as intercrops.

Chapter 3. MATERIALS AND METHODS

3.1 Description of the Study Site

The experiment was carried out at Adet Zuria (*kebele*), in Yilmana Densa district West-Gojjam Administrative Zone of Amhara Region, Northwest Ethiopia. The entire experimental site was geographically situated between 37°30'7"E and 11°15'29"N (Figure 1). The altitude of the study area ranges from 1800 -2300 m.a.s.l with a unimodal rain fall distribution with mean annual rainfall of 1270 -2300 mm. The daily minimum and maximum temperature ranges from 11.9 ^{o}C and 25.6 ^{o}C, respectively, and characterized by semi-humid climate. It is found at about 475 km away in north of Addis Ababa, Capital of Ethiopia and 45 km South of Bahir Dar, the capital of the Amhara Region. It is an agriculturally potential district that represents the middle part of the upper Blue Nile basin where the common food crops in the area are: teff, maize, wheat, haricot bean, field pea, beans, potato and others. The soil type of the study area is clay loam with PH of 5.8. Over all the area has diversified potential of crop productivity endowed with rich resources that is suitable to undertake the cropping system we are interested about. The common intercropped crops practiced in the area are maize with faba bean and maize with haricot bean (YDWAO, 2020).

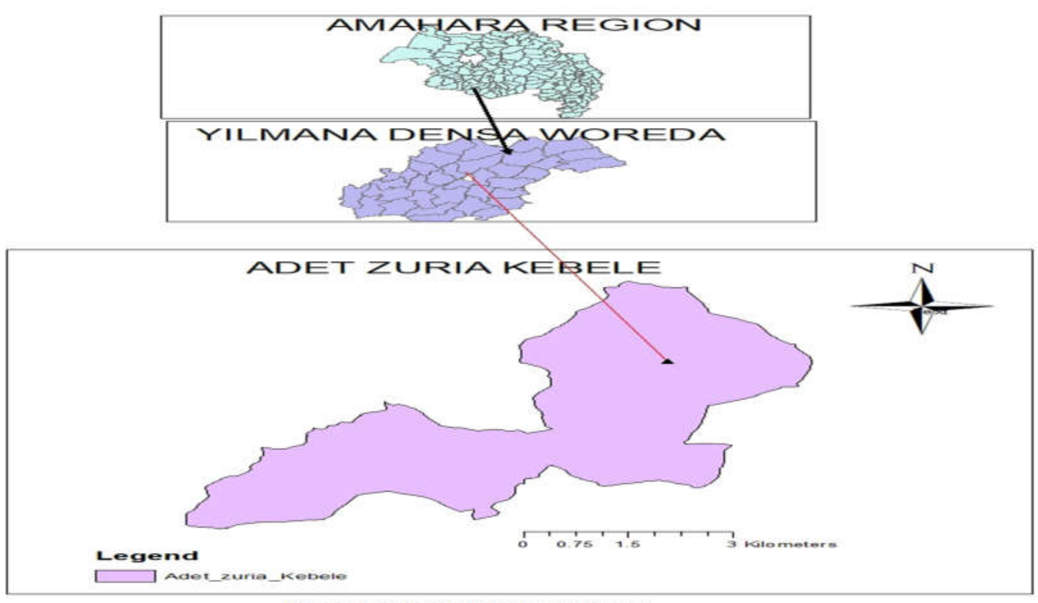

Figure 3.1 Map of the study area

3.2 Experimental Materials

3.2.1 Plant materials

Hybrid varieties of maize namely BH 661 and BH 546, and improved varieties of haricot bean namely; Lehode and Batu were used for the study. Both BH 661 and BH 546 are released by Bako Research Centre. BH 546 is a newly released variety adapted in rages of altitude between 1000-1750m above sea level. While BH 661 is the one among Bako hybrids of maize mostly grow best between midlands to highlands of the country in the altitudinal range between 1600-2200m above sea level. On the other hand, Haricot bean variety Lehode, which was released by Sirinka Agricultural Research Centre in 2010 and it, grows well at an altitude < 1850 m a.s.l. Batu is released by Melkasa agricultural researches centre in the year 2008 and has an altitudinal requirement of 1300-1950m a.s.l. The two crop varieties were selected for intercropping based on their adaptability in the area, differences in their morphological characteristics, resource requirement and yield potential. Thus, haricot bean variety Batu has extended canopy and broader leaves as compared to variety Lehode whereas maize variety BH 661 has taller plant height and wider canopy as compared to BH 546. Accordingly, maize varieties of BH 661 have taller growth habit and late maturing as compared to BH 546. Whereas haricot bean variety Batu have broader leaves and extended canopy than variety Lehode (MoA, 2014).

3.2.2 Fertilizer materials

For both sole and intercropped maize, the land was fertilized with total of 200 kg NPS per hectare and 200 kg UREA per hectare as per Yilmana Densa district recommendations for maize. All amounts of NPS fertilizer were applied at the time of sowing. The recommended amount of urea for maize was also applied 35-40 days after sowing. Separate fertilization with 100 kg NPS was made for the sole treatment of haricot bean at the time of sowing. Hence, for root facilitation NPS is required at time of sowing for mono cropped legume while intercropped haricot bean can get optimum fertilizer from the base crops inputs. The sources of nitrogen and phosphorous fertilizers were UREA and NPS (ABoANR, 2010).

3.3 Treatments and experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) in a factorial arrangement with sixteen treatments (two maize varieties, two haricot bean varieties, three times of sowing and four mono crop treatments) with three replications. The intra row and inter row spacing of 80 cm by 40 cm for BH 546 and 80 cm by 45 cm for BH 661 was maintained respectively, for both cropping systems (sole and intercrop). A plant population of 62,500 plants per hectare for BH 546 and 55,555 plants per hectare for BH 661 were maintained. Whereas for haricot bean, a spacing of inter and intra row spacing of 40 by 10cm^2 was used for both varieties and a total of 41,666 plants were grown in a hectare (ABoANR, 2010; MoA, 2014). As to the planting method, there were three time of planting of haricot bean (simultaneous sowing with maize, two weeks later and four weeks after maize sowing). The two varieties of haricot bean populations were inter planted with maize varieties in an additive series of intercropping arrangements at different time based on recommendations. The gross experimental area was 1632 m^2 (80m by 20.4 m) and the distance between the plots and blocks was kept 1 m and 2 m apart respectively. The gross and net plot area for maize was 19.2 m^2 and 11.52m^2 (3.2 by 3.6), respectively. On the other hand, 15.2m^2 (4m by 3.8m) and 3.04m^2 (0.8m by 3.8m) net plot areas were utilized for mono cropped and intercropped haricot bean data collections, respectively.

3.4 Experimental Procedure

Appropriate site was selected and ploughed for about four times. Following final land preparation each of the sixteen treatments were allocated in a block randomly using random number table with three replications. Each plot was consisted six rows of maize for both mono and intercropping. On the other hand, for mono crop haricot bean twelve rows and two inter crop rows were there. The fertilizer material was measured for each plot and was distributed uniformly. Double seeds of maize and haricot bean seed at each spot were used for planting to obtain the required stand. The required amount of fertilizer per spot was put 5cm away from the seed. Sole and intercropped maize were planted on beginning of June. The companion crops were planted accordingly with specified day of plantings.

3.5 Data Collected

3.5.1 Maize

Crop phenological parameters

Days to 50 % tasselling: was recorded when 50 % of the plants in a plot display tassels with the aid of visual observation.

Days to 90 % maturity: the days to 90 % maturity was taken when 90 % of the plants in a plot develops black layer near the attachment of the cob.

Crop growth parameters

Number of leaves per plant: the number of leaves per plant was taken from five randomly selected plants in a net plot area and their average was taken after physiological maturity.

Plant height (m): Plant height was recorded as the height of plant grown from the ground level to the base of the tassel from five randomly sampled plants at the end of 90% physiological maturity in each plots net area.

Figure 3.2. Experimental field at the time of maize maturity and plant height measurements

Yield and yield related traits

Number of cob per plant: The number of cob produced per plant of the central four sampling rows was recorded after physiological maturity and their average was taken.

Ear length (cm): ear length was measured starting from the base to the apex of the ear after physiological maturity of five randomly selected ears from the net plot area.

Ear diameter (cm): The diameter of the ear was measured using calliper from five randomly selected ears in the net plot area after maturity and their average was taken.

Biomass yield (kg): The above ground biomass yield was measured after sun drying for two weeks by weighting all the above ground parts of the plants in the plots net area including grains.

Grain yield (kg): maize yield was measured from the net plot area and expressed as kg/ha. Maize yield was adjusted to 12-13 % moisture using a digital moisture tester.

$$Adjusted\ yield = \frac{100 \quad Actual\ moisture}{100 \quad Standard\ moisture} \quad X \quad Obtained\ yield$$

Harvest index: Harvest index was measured by dividing the weight of the grain to the total weight of above ground biomass in each plot after weighing the respective yields.

Hundred kernels weight (g): The sample of a hundred maize kernels were taken from seed lot of each plots net area and expressed in grams.

3.5.2 Haricot bean

Crop phenological parameters

Days to 50 % flowering: was recorded when 50 % of the plants in a plots net area produce flowers with the aid of visual observation.

Days to 90 % maturity: was recorded when the first pod of 90 % of the plants in a net plot area physiologically matures by the aid of visual observation.

Crop growth parameters

Plant height (cm): Plant height was recorded as the height of plant grown from the ground level from five randomly sampled plants at 90 % physiological maturity in each plots net area.

Yield and yield related traits

Number of pods per plant: Number of pods was counted from the same ten randomly selected plants after harvest in each plots net area.

Number of seeds per pod: was taken from the same five randomly selected pods after harvest and each of seeds counted manually in each plots net area.

Biomass yield (kg): The above ground biomass yield was measured after sun drying for a week by weighting all the above ground parts of the plants in the plots net area including grains.

Grain yield (kg): haricot bean yields were measured from the net plot area and expressed as kg/ha. Haricot bean yield was adjusted to 12 % moisture using a digital moisture tester.

$$Adjusted\ yield = \frac{100 \quad Actual\ moisture}{100 \quad Standard\ moisture} \quad X \quad Obtained\ yield$$

Harvest index: Harvest index was measured by dividing the weight of the grain to the total weight of above ground biomass in each plot after weighing the respective yields.

Hundred kernels weight (g): The sample of a hundred haricot bean kernels were taken from seed lots of each plots net area and expressed in grams.

Figure 3.3. Measurement of hundred kernels weight of haricot bean

2.6 Data Analysis

2.6.1 Stasticial data analysis

The Analysis of Variance (ANOVA) and the correlation of agronomic parameters were analysed using SAS GLM procedures 9.4 version. Least significant difference (LSD) test at 5 % probability level was used for mean separation when the analysis of variance indicates the presence of significant differences among the treatments (Gomez and Gomez, 1984).

2.6.2 Productivity data analysis

Land Equivalent Ratio (LER)

Land use efficiency and productivity of the system was analysed using the following methods. Land Equivalent Ratio (LER) is the most frequently used efficient indicator. LER can be defined as the relative land area used under sole crop that would be required to produce the equivalent yield under an intercrop at the same level of management.

Land equivalent ratio (LER) =

$$\frac{yield\ of\ intercrop\ maize}{yield\ of\ sole\ maize} + \frac{yield\ of\ intercrop\ \ aricot\ bean}{yield\ of\ sole\ \ aricot\ bean}$$

After computing, when LER = one there is complementarity between component crops. When the LER is greater than one, the intercropping favours the growth and yield of the species. In contrast, when LER is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures (Willey and Osiru, 1972).

Area Time Equivalent Ratio (ATER)

The area time equivalent ratio takes in to account the duration of the intercrops in intercropping systems in the field and also evaluated the crop yield per day basis takes to reach harvest maturity. It was calculated by the summation of component crops LER multiplied with respective durations for maturity divided by the total time taken to complete the system.

Area time equivalent ratio (ATER) =

$$\frac{LER\ of\ maize\quad duration\ of\ maize + LER\ of\quad aricot\ bean\quad duration\ of\quad aricot\ bean}{Total\ time\ required\ for\ t\quad e\ system}$$

Thus, when the ATER is greater than one, intercropping enhanced the growth and yield of the component crops. On the contrary, when ATER was lower than one, intercropping negatively affected the growth and yield of the component crops (Hiebsch and McCollum, 1987).

2.6.3 Profitability data analysis

Monetary Advantage Index (MAI)

Monitory advantage index was calculated by multiplying the respective yields of the component crops by their local market prices during the experiment and divided by respective LER. The average local market prices of maize, Batu and Lehode grain were 9, 22 and 20 ETB per kilo gram, respectively from December to January.

Monetary advantage index (MAI) =

$$\frac{Value\ of\ combined\ intercropped\ yield\ \times\ (LER\quad 1)}{LER}$$

Following the calculations a treatment with the highest monetary value was identified (Willey, 1979).

Partial budget analysis

Partial budget analysis is an effective technique for assessing the profitability of comparative treatments. It also provides the foundation for comparing the relative profitability of alternative treatments, evaluating their riskiness and testing how robust profits are in the event of changing product or input prices. Thus, the data were analysed based on the revised manual published by the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT, 1988). It takes in to account the analysis of Total Variable Cost (TVC), Gross Benefit (GB), Net Benefits (NB) and finally the analysis of Marginal Rate of Return (MRR).

The grain and stalk yield of maize was adjusted to narrow yield gap between experimental plots and farmer's field, which means multiplying respective yield by 0.9. The production costs which show variation (maize seed, haricot bean seed and labour costs) between treatments were identified and converted to per hectare bases. The seed cost of BH 661, BH 546 Batu and Lehode were 30 Birr, 18 Birr, 22 Birr and 16 Birr per kilo gram, respectively. The gross benefit was computed by multiplying the grain and straw yields of the maize crop by their own local market price and adding them together. A sale price for maize, Batu and Lehode was 9 Birr, 22 Birr and 20 Birr per kilogram respectively, as per two months average (December to January). Net benefit was computed by subtracting the total cost of production from the gross benefit obtained. Finally the profitable and economical treatment was identified and recommended for final users.

All treatments were first listed in order of increasing total variable costs for the purpose of dominance analysis to simplify subsequent calculations by ignoring inferior treatments. Any treatment with net benefits less than or equal to those of a treatment with lower cost is considered to be dominated (i.e., inferior). Dominated treatments are omitted from subsequent steps in the marginal analysis. The marginal rate of return was calculated by ratio of marginal net benefit to marginal variable costs, expressed as a percentage. Finally, marginal analysis involved comparing the MRR between treatments to the minimum rate of return acceptable to farmers. All the treatment examined for marginal rate of return analysis was scored MRR greater than 100 % which was acceptable.

2.6.4 Analysis of competitive function

Competitive Ratio (CR)

Competition between component crops was measured by the CR (Zhang *et al*., 2014). The CR of the component crops was calculated by the formula:

$$CR/AV = LERa \quad LERb$$

Where, LERa and LERb are the first and second component crops, respectively. CR > 1, indicate the first crop is competitor, while values < 1 implicates the second component crop is profusely suppressed the first crop. Computed value of one indicates no effect of competition up on intercropping of component crops.

Chapter 4. RESULTS AND DISCUSSION

4.1 Maize Components

4.1.1 Crop phenological parameters

Days to 50 % tasselling

The analysis of variance showed that days to 50 % tasselling of maize was very highly significantly ($P < 0.001$) affected by main effect of maize varieties. The main effects of haricot bean varieties, planting time and their interaction were not significantly ($P > 0.05$) affect days to 50 % tasselling of maize (Appendix Table 1). Accordingly, variety BH 661 was late (89.77 days) to produce fifty percent tassels while variety BH 546 appeared fifty percent tassels within 80.05 days (Table 4.1). The variation in days to tasselling might be inherent genotypic characteristic of the varieties.

Table 4.1 Main effect of maize varieties on days to 50 % tasselling and days to 90 % physiological maturity of the maize

Treatments	Phenological parameters	
	Days to 50 % tasselling	Days to 90 % physiological maturity
Maize varieties		
BH 546	80.05b	128.61[b]
BH 661	89.77[a]	149.55[a]
LSD (0.05)	**0.56*** **	**1.15*** **
SE±	**0.43**	**0.39**
CV	**6.81**	**9.58**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; ***= very highly significant*

The comparison between sole and intercropped maize revealed that there was no significant ($P > 0.05$) difference in days to fifty percent tasselling due to cropping system of same variety. However, in the over-all comparisons mono cropped and intercropped BH 661 took extended times (90.66 and 89.77 days), respectively. Whereas, mono cropped and intercropped BH 546 took shortened (81.0 and 80.05 days, respectively) days to reach 50 % tasseling (Table 4.2). This variation in the over-all comparison might be resulted from differences in the inherent varietal phenology of BH 546 and BH 661.

Days to 90 % physiological maturity

The analysis of variance showed that days to ninety percent physiological maturity of maize was very highly significantly ($P < 0.001$) affected by main effect of maize varieties. On the other hand, the main effects of haricot bean varieties, planting time and their interactions were not significantly ($P > 0.05$) affecting days to ninety percent physiological maturity of maize (Appendix Table 1). Hence, variety BH 661 was take the longest days (149.55 days) to reach ninety percent physiological maturity while variety BH 546 reached to ninety percent physiological maturity within 128.61 days (Table 4.1). With regard to main effect of haricot bean varieties similar findings were reported by Jibril Temesgen *et al.* (2015) who showed common bean varieties as well as cropping system had no significant effect on the days to physiological maturity of maize.

The comparison between sole and intercropped maize revealed that there was no significant ($P > 0.05$) difference in days to ninety percent physiological maturity due to cropping system of same variety. However, in the over-all comparisons mono cropped and intercropped BH 661 took extended times (150.66 and 149.55 days), respectively. Whereas, mono cropped and intercropped BH 546 took shortened (81.0 and 80.05 days, respectively) to reach ninety percent physiological maturity (Table 4.2). This variation in the over-all comparison might be resulted from differences in the inherent varietal phenology of BH 546 and BH 661. This result contradicts with the finding of Sisay Tekle (2004) who described and reported non-significant effect of cropping system on physiological maturity of maize.

Table 4.2. Effect of sole planting and intercropping treatments on days to 50 % tasselling, days to 90 % physiological maturity, plant height (m) and number of leaves per plant of maize

Treatments	Maize parameters			
	DFTM	DMM	PHM	NLPM
Sole BH 546	81.00^{b}	130.00^{b}	1.90^{c}	15.93^{ab}
Sole BH 661	90.66^{a}	150.66^{a}	2.88^{a}	16.46^{a}
Intercropped BH 546	80.05^{b}	128.61^{b}	1.85^{d}	15.08^{c}
Intercropped BH 661	89.77^{a}	149.55^{a}	2.82^{b}	15.63^{bc}
LSD (P<0.05)	**1.27****	**1.77****	**0.025***	**0.8***
SE±	**0.43**	**0.58**	**0.008**	**0.27**
CV (%)	**5.81**	**1.69**	**7.25**	**7.1**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; DFTM= days to fifty percent tasselling; DMM= days to maturity ninety percent maturity; PHM= plant height; NLPM= number of leaf per plant; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; ***= very highly significant; m= meter.*

4.1.2 Growth parameters

Plant height

The analysis of variance showed that plant height of maize was very highly significantly ($P < 0.001$) affected by main effect of maize varieties and time of sowing. Whereas, main effects of haricot bean varieties and their interactions were not significantly ($P > 0.05$) affected maize plant height (Appendix Table 2). Variety BH 661 showed the highest plant height of 2.82 m as the lower plant height (1.85 m) was recorded from variety BH 546. With regard to time of sowing, maize planted simultaneously with haricot bean had recorded the lowest plant height (2.31 cm) while the highest (2.35 m) was recorded in maize intercropped with haricot bean four weeks after it's sowing (Table 4.3). Variations in plant height of maize due to maize varieties could arise from differences in genetic makeup of varieties. With regard to time of sowing, similar findings were stated by Demissie Alemayehu *et al*. (2017) who notified that higher maize plant height were recorded when common bean varieties were planted four weeks after maize emergency and the trend of increased height were observed with delayed under seeding of common bean varieties.

The analysis of variance for cropping system revealed that there was significant (P < 0.05) difference in plant height of maize. Accordingly, the highest plant height (2.88 m) was observed in mono cropped variety BH 661 while the lowest (1.85m) was observed in intercropped BH 546 (Table 4.2). This result was supported by Hirpha Dechasa (2005) who reported that height of sole cropped sorghum was significantly higher than intercropped sorghum. Furthermore, Demissie Alemayehu *et al*. (2017) confirmed that sole cropped maize had significantly higher plant height (255.2 cm) than the intercropped system and the reduction of height of the intercropped maize might be associated with interspecific competition between the intercrop components for growth resources (light, water, nutrients etc.) and depressive effects of common bean on maize at early growth stage because both crop were planted simultaneously and bean was emerged early than maize.

Table 4.3. Main effect of component crops varieties and haricot bean planting time on plant height (m), number of leaves per plant, number of cobs per plant and ear length (cm) of maize

Treatments	Maize characters			
	PHM	NLPM	NCPM	ELM
Maize varieties				
BH 546	1.85^{b}	15.08^{b}	1.52^{b}	17.68^{b}
BH 661	2.82^{a}	15.62^{a}	1.66^{a}	18.43^{a}
LSD (0.05)	**0.01*** **	**0.33*** **	**0.06*** **	**0.52** **
Haricot bean varieties				
Batu	2.34NS	15.42NS	1.60NS	17.68^{b}
Lehode	2.33NS	15.28NS	1.58NS	18.42^{a}
LSD (0.05)	**0.01NS**	**0.33NS**	**0.06NS**	**0.052** **
Sowing Time				
Simultaneous	2.31^{c}	14.90^{b}	1.50^{c}	18.08NS
Two weeks later	2.34^{b}	15.26^{b}	1.58^{b}	18.09NS
Four weeks later	2.35^{a}	15.89^{a}	1.69^{a}	17.98NS
LSD (0.05)	**0.014*** **	**0.4*** **	**0.08*** **	**00.63NS**
SE±	**0.009**	**0.27**	**0.05**	**0.43**
CV	**6.7**	**8.05**	**9.85**	**9.17**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; PHM= plant height; NLPM= number of leaf per plant; NCPM= number of cob per plant; ELM= ear length of maize; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; rep= replication; NS= non-significant; ***= very highly significant; m= meter; cm= centimetre*

Number of leaves per plant

The analysis of variance showed that number of leaves per plant of maize was very highly significantly (P < 0.001) affected by main effect of maize varieties and time of sowing. All the interaction effects and main effect of haricot bean varieties were not significantly (P > 0.05) affected number of leaves per plant (Appendix Table 2). Thus, higher leaf numbers per plant (15.62) was recorded in variety BH 661 while the lower (15.08) was observed in BH 546 variety. With regard to effect of time of sowing, maize intercropped with haricot bean four weeks after its sowing showed the highest (15.89) leaf numbers whereas, simultaneously intercropped maize with haricot bean recorded the lowest leaf numbers (14.90) (Table 4.3). The respective increments of leaf numbers per plant of maize with late sowing of component crop might be resulted from limited competition for growth resources of poorly established late sown legumes.

The comparison result between sole and intercropped haricot bean showed that there was significant (P < 0.05) difference in leaf numbers per plant of maize. Accordingly, mono cropped varieties of BH 661 and BH 546 recorded the highest (16.46 and 15.93, respectively) leaf numbers per plant while the lowest leaf numbers (15.63 and 15.08) were observed in both intercropped varieties of BH 546 and BH 661, respectively (Table 4.2). This result contradicts with Anyaegbu (2014) findings who stated that the number of leaves per plant was not significantly (P> 0.05) affected by cropping system.

4.1.3 Yield and yield related components of maize

Number of cobs per plant

The analysis of variance showed that number of cobs per plant of maize was very highly significantly (P < 0.001) affected by main effect of maize varieties and time of sowing. All interaction and main effect of haricot bean varieties were not significantly (P > 0.05) affected number of cobs per plant of maize (Appendix Table 2). The higher cob numbers per plant (1.66) was recorded in maize variety BH 661 while lower (1.52) was recorded in BH 546 variety. With regard to sowing time, the maximum (1.69) and minimum (1.5) cob numbers per plant were recorded in maize intercropped with haricot bean four weeks after it's sown and intercropped simultaneously, respectively (Table 4.3). With regard to maize variety similar findings were reported by Alom *et al*. (2009) who confirmed the maximum and minimum cob numbers per plat was obtained in variety Pacific 984 & Pacific 11, respectively. On the other hand, Teshome Gutu *et al*. (2015) describe significant effect of soybean varieties on number of cobs per plant of maize which contradict with the result.

The comparison result between sole and intercropped maize indicated that there was highly significant ($P < 0.01$) difference in cob numbers per plant of maize. Accordingly, both sole cropped varieties of BH 661 and BH 546 recorded the highest cob numbers per plant of maize (1.86 and 1.73, respectively) whereas the lowest (1.63 and 1.52) was observed in intercropped BH 661 and BH 546, respectively (Table 4.4). The higher cob numbers per plant in mono cropped treatments might be due to reduced competition effects for resources. In line with this result Alom *et al*. (2009) reported that sole cropped hybrid maize variety Pacific-11 recorded the highest (1.22) cob numbers per plant while the lowest (1.03) was observed in the intercropped maize hybrid variety Pacific 984 with ground nut.

Table 4.4. Effect of sole planting and intercropping treatments on number of cobs per plant, ear diameter (cm) and grain yield (kg/ha) of maize

Treatments	Maize characters		
	Number of cobs per plant	Ear diameter	Grain yield
Sole BH 546	1.73[ab]	4.12[b]	7459.6[b]
Sole BH 661	1.86[a]	4.24[a]	9315.0[a]
Intercropped BH 546	1.52[c]	3.89[c]	6307.05[c]
Intercropped BH 661	1.63[bc]	3.98[c]	7855.48[b]
LSD (P<0.05)	**0.18*** **	**0.11*** **	**558.25*** **
SE±	**0.06**	**0.036**	**192.04**
CV (%)	**10.01**	**6.79**	**9.73**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; ***= very highly significant; cm= meter; kg/ha= kilo gram per hectare.*

Ear length

The analysis of variance revealed that ear length of maize was highly significantly ($P < 0.01$) affected by main effect of maize varieties and haricot bean varieties. On the other had main effect of sowing time and their interactions did not significantly affect ear length ($P > 0.05$) (Appendix Table 2). With regard to effect of maize varieties, the higher (18.43 cm) and lower (17.68 cm) ear lengths were recorded in maize varieties of BH 661 and BH 546, respectively. While maize intercropped with haricot bean variety Lehode recorded the highest ear length (18.42 cm) and those intercropped with variety Batu was the lower (17.68 cm) ear length (Table 4.3). The analysis of variance for cropping system indicated that there was no significant ($P > 0.05$) difference in ear length of maize (Appendix Table 5).

The variation in ear length of maize with varietal differences of component crops might be due to variable nature of varieties in resource utilization efficiency which will have direct effect in growth and yield component of the crop. With regard to effect of maize varieties similar findings were reported by Alom *et al*. (2009) who reported the maximum and minimum ear lengths were recorded in maize varieties of Pacific-984 and Pacific-11 respectively.

Ear diameter of maize

The analysis of variance showed that ear diameter of maize was very highly significantly ($P < 0.001$) affected by main effect of maize varieties, haricot bean varieties and time of sowing and three-way interaction effect of maize variety, haricot bean variety and sowing time was significantly ($P < 0.05$) affected ear diameter. On the other hand, all the two-way interaction effects did not significantly ($P > 0.05$) affect ear diameter except haricot bean variety with time of sowing which had affect very highly significantly affected ear diameter ($P < 0.001$) (Appendix Table 2). Thus, concerning three-way interaction effects, the highest ear diameter of maize (4.32 cm) was recorded when variety BH 661 intercropped four weeks after its sowing with variety Batu and the lowest (3.60 cm) was obtained on variety BH 546 simultaneously intercropped with variety Lehode (Table 4.5). With respect to varietal effect of maize, similar findings were reported by Alom *et al*. (2009) who ascertained varietal effects result in variation in ear diameter of maize.

Table 4.5.Three-way interaction effect of maize varieties and time of intercropping of haricot bean varieties on ear diameter (cm) of maize in maize-haricot bean intercropping system

Maize varieties	Maize Parameter		
	Haricot bean varieties	Time of sowing	Ear diameter of maize
		Simultaneous	3.89[fg]
	Batu	Two weeks later	3.83[gh]
		Four weeks later	4.036[cde]
BH 546		Simultaneous	3.60[i]
	Lehode	Two weeks later	3.88[fg]
		Four weeks later	3.72[h]
		Simultaneous	4.14[bc]
	Batu	Two weeks later	4.22[ab]
		Four weeks later	4.32[a]
BH 661		Simultaneous	3.97[ef]
	Lehode	Two weeks later	4.10[dc]
		Four weeks later	4.03[de]
LSD			**0.11***
SE±			**0.04**
CV			**6.55**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; *= significant; cm= centimetre.*

The comparison result between sole and intercropped haricot bean showed that there was very highly significant (P < 0.001) difference in ear diameter of maize varieties. The higher ear diameter of maize (4.24 cm) was recorded from mono cropped BH 661 and the lower (3.98cm and 3.89cm) was obtained on intercropped BH 661 and BH 546, respectively (Table 4.4). In agreement with this result Alom *et al*. (2009) announce that mono cropped variety Pacific 11 recorded the highest ear diameter whereas, intercropped variety BHM-1 was the lowest.

Grain yield

The analysis of variance showed that grain yield of maize was very highly significantly ($P < 0.001$) affected by main effect of maize varieties and two-way interaction effects of haricot bean varieties with time of sowing. The remaining interaction effects did not affect grain yield significantly ($P > 0.05$) (Appendix Table 3). With regard to main effect of maize varieties, the higher grain yield of maize (7817.7 kg/ha) was obtained from BH 661 while the lower (6307 kg/ha) was recorded from BH 546 (Table 4.6). This variation in maize yield due to maize varietal differences might be resulted from the inherent high yielding potential and agro ecological adaptation of the varieties.

Table 4.6. Main effect of maize varieties on grain yield (kg/ha) of maize in maize-haricot bean intercropping system

Maize varieties	Grain yield
BH 546	6307^{b}
BH 661	7817.7^{a}
LSD	**213.09*** **
SE±	**177.97**
CV	**9.36**

Note: *kg/ha = kilo gram per hectare; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; ***= very highly significantly*

On the other hand, two-way interactions of haricot bean varieties with time of sowing showed that the higher (7922.6 kg/ha) and lower (5979.2kg/ha) maize grain yields were obtained when haricot bean variety Batu intercropped four weeks after maize sowing and haricot bean variety Lehode intercropped simultaneously, respectively (Table 4.7). This might be due to minimum competitive ability of late sown legumes for nutrient, water and sunlight with early emerged cereal component. Similar with this result Demissie Alemayehu *et al.* (2017) who reported that simultaneous intercropping reduces maize grain yield by 31.9 % as compared to intercropping six weeks after maize emergency which indicates an increased trend of mean grain yield of maize with delaying the time of common bean intercropping. Furthermore, Chemeda Fininsa (1997) also reported that delayed bean planting increased maize grain yield in maize/bean cropping systems.

Addo-Quaye *et al.* (2011) also reported that time of introduction of soybean significantly affected maize grain yield and delayed soybean planting increased maize grain yield in maize/soybean cropping system. With regard to interaction effect of haricot bean varieties with time of sowing similar result was reported by Zerihun Abebe *et al*. (2016) who confirmed that the highest maize yield was recorded when bean was intercropped 20 days after BH 546 variety was planted though comparable yield was also obtained from BH 661. Gibe 2 was significantly dominated by climbing bean when planted simultaneously and the yield was significantly reduced compared to hybrid varieties. However, the current result contradicted with Jibril Temesgen *et al*. (2015) who stated that there were highly significant differences in grain yield of maize due to the main effect of legume variety.

Table 4.7. Two-way interaction effect of haricot bean varieties with time of sowing on grain yield (kg/ha) of maize in maize-haricot bean intercropping system

Haricot bean varieties	Maize character	
	Time of sowing	Grain yield
	Simultaneous	6920.4^{abc}
Batu	Two weeks later	6764.3^{bc}
	Four weeks later	7922.6^{b}
Lehode	Simultaneous	5979.2^{c}
	Two weeks later	7357.4^{ab}
	Four weeks later	7430.3^{ab}
LSD		**1077.1*****
SE±		**525.84**
CV		**12.95**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; ***= very highly significantly; kg/ha = kilo gram per hectare*

The comparison result between sole and intercropped maize revealed that there was very highly significant (P < 0.001) difference in grain of maize. Accordingly, variety BH 661 sole cropped obtained the highest grain yield of maize (9315 kg/ha) whereas, the lowest (6307.05 kg/ha) was obtained in intercropped BH 546 (Table 4.4). This might be resulted due to coupled effect of varietal differences and interspecific competition from component crops in the intercropping system. In line with this result Belsite Lulie *et al.* (2016) notified that cropping system showed significant effect on grain yield of maize. As per their findings, maximum grain yield (7.87 ton per hectare) was obtained from sole cropping system of maize while the lower grain yield (7.07 ton per hectare) was maintained for intercropped maize. The amounts of yield reduction over sole crop were 10 %. This suggests lower intra-specific competition of sole maize for natural resources (light, water and nutrients) compared to maize intercropped with haricot bean and also revealed effective utilization of applied nitrogen and phosphorus fertilizer by sole maize. More over, Ejigu Ejara *et al.* (2017) revealed that cropping system significantly affected maize grain yield. Consequently, maize sole cropping had significantly higher grain yield than intercropped maize. Thus, yield advantage of sole maize had 47 % and 50 % over maize grain yield in 2012 and 2011 cropping season, respectively.

Above ground biomass yield

The analysis of variance showed that above ground biomass yield of maize was not significantly ($P > 0.05$) affected by main and interaction effect of maize varieties, haricot bean varieties and time of sowing (Appendix Table 3). Similar with this result Teshome Gutu *et al*. (2015) reported none significant ($P > 0.05$) effect of soybean varieties on above ground biological yield of maize. The comparison result between sole and intercropped haricot bean also showed that there was not significant ($P > 0.05$) difference in above ground biomass yield of maize (Appendix Table 5).

Harvest index

The analysis of variance showed that harvest index of maize was not significantly ($P > 0.05$) affected by main and interaction effect of maize varieties, haricot bean varieties and time of sowing (Appendix Table 3). The comparison result between sole and intercropped haricot bean also showed that there was not significant ($P > 0.05$) difference in harvest index of maize (Appendix Table 5). In line with this result Tamado Tana *et al*. (2007) reported non-significant effect of common bean varieties and cropping system on harvest index of maize in

2004 growing season both in Alemaya and Hima areas. Moreover, Solomon Kebebew *et al*. 2014 noted that soybean varietal differences had no significant effect on harvest index of maize.

Hundred kernels weight

The analysis of variance showed that hundred kernel weight of maize was not significantly ($P > 0.05$) affected by main and interaction effect of maize varieties, haricot bean varieties and time of sowing (Appendix Table 3). The comparison result between sole and intercropped haricot bean also showed none significant ($P > 0.05$) difference in hundred kernels weight of maize (Appendix Table 5). Similar findings were obtained by Alom *et al*. (2009) revealed that the hundred kernels weight of maize did not differ by the intercropping systems. Moreover, Tamado Tana *et al*. (2007) reported non-significant effect of common bean varieties and cropping system on thousand kernel weight of maize in (2004) growing season both in Alemaya and Hima areas.

4.2 Haricot Bean Components

4.2.1 Phenological parameters

Days to 50 % flowering

The analysis of variance revealed that main effect of maize varieties and times of sowing were significantly ($P < 0.05$) and highly significantly ($P < 0.01$) affected days to fifty percent flowering, respectively. On the other hand, the interaction effects did not show significant differences on days to flowering ($P > 0.05$) (Appendix Table 6). Haricot bean intercropped with BH 661 maize variety reached to fifty percent flowering on average of 49.66 days whereas, haricot bean intercropped with BH 546 maize variety reached to fifty percent flowering within 52.11 days. With regard to main effect of time of sowing, simultaneous sown haricot bean appeared fifty percent flowering with an average of 52.41 days as compared to haricot beans intercropped four weeks after maize sowing which took 48.91 days to flower (Table 4.8).

The early flowering of haricot bean intercropped with BH 661 might be due to the increased maize canopy leads to inter specific competition for resources (especially sunlight) as compared to BH 546 having lower growth habit. An extensive reduction of days to flowering of haricot bean was observed with delayed planting of haricot bean than others. Late planting of haricot bean four weeks after maize planting resulted in week stand establishment and early flowering which might be due to increased shading effect by maize plants and reduced availability of resources for growth and development. Concomitant findings were reported by Demissie Alemayehu *et al*. (2018) stating variety Haramaya, Ibbado and Hawassa Dume reached to flower initiation on average of 48, 45 and 41.8 days for simultaneous intercropping, respectively, while these varieties took on average 44, 40 and 36 days when intercropped at two weeks after maize emergency. The flower initiation was further reduced to 33 to 34 days when these varieties were intercropped at four weeks after maize emergency.

Table 4.8. Main effect of maize varieties and haricot bean sowing time on days to 50 % flowering and days to 90 % physiological maturity of haricot bean in maize-haricot bean intercropping system

Treatments	Phenological parameters	
	Days to 50 % flowering	Days to 90 % physiological maturity
Maize varieties		
BH 546	52.11^{a}	80.61NS
BH 661	49.66^{b}	82.44NS
LSD (0.05)	**0.61***	**0.64NS**
Sowing Time		
Simultaneous	52.41^{a}	85.00^{a}
Two weeks later	51.33^{b}	81.08^{ab}
Four weeks later	48.91^{c}	78.50^{b}
LSD (0.05)	**0.74****	**4.46***
SE±	**0.51**	**3.04**
CV	**8.89**	**6.75**

Note: *Means with similar letters in the same column are not significantly different at P<0.05;* LSD= *least significance difference; SE±= standard error of mean; CV= coefficient of variation; *= significant; **= highly significant.*

The comparison result between sole and intercropped haricot bean indicated that there was highly significant (P < 0.01) difference in days to fifty percent flowering of haricot bean. Among the treatments longest days to flowering (52.33 and 51.66) was recorded from sole crop varieties of Lehode and Batu, respectively as compared to intercropped Lehode and Batu which took only 50.50 and 50.27 days, respectively for fifty percent flowering (Table 4.9). This could be due to increased competition from well-established maize crop in intercropping system than monocrops having full access of growth resources leading to extended growth periods. In line with this result Demissie Alemayehu *et al*. (2018) notifies intercropping resulted in shorter days to flowering compared to sole cropping of all common bean varieties.

Table 4.9. Effect of sole planting and intercropping treatments on days to 50 % flowering and days to 90 % physiological maturity of haricot bean.

Treatments	Haricot bean characters	
	Days to 50 % flowering of HB	Days to 90 % physiological maturity of HB
Sole Batu	51.66^{ab}	84.66^{a}
Sole Lehode	52.33^{a}	85.66^{a}
Intercropped Batu	50.27^{b}	81.39^{b}
Intercropped Lehode	50.50^{b}	81.72^{b}
LSD (P<0.05)	**1.44****	**1.89****
SE±	**0.49**	**0.65**
CV (%)	**7.31**	**6.85**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; HB= haricot bean; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; **=highly significant*

Days to 90 % physiological maturity

The analysis of variance showed that days to ninety percent physiological maturity of haricot bean significantly (P < 0.05) affected by main effect of time of sowing. The remaining main and interaction effects did not affect significantly (P > 0.05) days to ninety percent physiological maturity (Appendix Table 6). Hence, haricot bean variety sown simultaneously with maize took longest days to matured physiologically (85 days) while haricot bean variety sown four weeks after maize sowing was matured within 78.50 days (Table 4.8). Similar to days to fifty percent flowering delaying haricot bean sowing to four weeks after maize planting was reached to maturity with reduced days might be due to increased resource competition from well-established maize plants and canopy closure.

The analysis of variance for cropping system showed that there was highly significant ($P < 0.01$) difference in days to ninety percent maturity of haricot bean. The highest time (85.66 and 84.66) days took to reach 90 % physiological maturity was recorded in mono cropped Lehode and Batu, respectively. On the other hand, intercropped varieties Lehode and Batu reached to ninety percent physiological maturity on average of 81.72 and 81.39 days, respectively (Table 4.9). Significant variations in days to maturity of sole and intercropped haricot bean varieties might be arise from greater competition in an intercropping system for available resources makes intercropped haricot beans to mature early.

4.2.2 Growth parameters

Plant height

The analysis of variance showed that main effect of maize and haricot bean varieties significantly ($P < 0.05$) affected haricot bean plant height. In the same way time of sowing and two-way interaction effect of maize varieties with sowing time and haricot bean varieties with time of sowing highly significantly ($P < 0.01$) affected plant height of haricot bean. However, three-way interaction effects and two-way effects of maize varieties and haricot bean varieties did not show significant differences (Appendix Table 7).

Thus, variety Batu sown simultaneously with maize verities recorded the taller (64.33 cm) plant height as compared to variety Lehode (49.83 cm) sown four weeks after maize sowing. With regard to two-way interaction effect of maize varieties with time of sowing, haricot bean varieties sown simultaneously with BH 546 recorded greater plant height (64.26 cm) whereas the shorter plant height (50.73 cm) was obtained in haricot bean varieties sown four weeks after BH 661 sowing (Table 4.10 and Table 4.11).

Table 4.10. Two-way interaction effect of haricot bean varieties with time of sowing on plant height (cm) of haricot bean

Haricot bean varieties	Haricot bean character	
	Time of sowing	Plant height
Batu	Simultaneous	64.33^{a}
	Two weeks later	60.70^{b}
	Four weeks later	52.13^{d}
Lehode	Simultaneous	62.83^{a}
	Two weeks later	54.10^{c}
	Four weeks later	49.83^{e}
LSD		**1.76****
SE±		**0.86**
CV		**7.6**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; **= highly significant; cm= centimetre*

This variation might be resulted from varietal difference and weak competitive ability of respective plantings of haricot bean for resources that determine the growth and development of the crop. This result was in agreement with Demissie Alemayehu *et al.* (2018) reporting a general trends of drastic decline plant height of haricot bean varieties were observed with delayed intercropping and also the overall poorest growth was observed.

Table 4.11. Two-way interaction effect of maize varieties with time of sowing on plant height (cm) of haricot bean

Maize varieties	Haricot bean character	
	Time of sowing	Plant height
	Simultaneous	64.26^{a}
BH 546	Two weeks later	58.96^{b}
	Four weeks later	51.23^{d}
BH 661	Simultaneous	62.9^{a}
	Two weeks later	55.83^{c}
	Four weeks later	50.73^{d}
LSD		**2.99****
SE±		**1.46**
CV		**9.42**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; **= highly significant; cm= centimetre*

The analysis of variance for cropping system showed that there was significant ($P < 0.05$) difference in plant height of haricot bean (Table 4.13). Accordingly, the highest plant height was observed in sole cropped Batu (70.80 cm) whereas the lowest was recorded in intercropped Lehode (55.59 cm). Similar findings were reported by Addisu Getahun and Seltene Abady (2016) where the highest plant height was recorded from sole cropped variety Awash Melka but the lower plant height was recorded from intercropped common bean with maize. Moreover, Yayeh Bitew (2014) also notified that sole lupine showed the highest plant height than under cereal/lupine intercropping.

4.2.3 Yield and yield components of haricot bean

Number of pods per plant

The analysis of variance revealed that main effect of maize and haricot bean varieties significantly ($P < 0.05$) affects number of pods per plant of haricot bean. Time of sowing also very highly significantly ($P < 0.001$) affected number of pods per plant (Table 12). On the other hand, any of the interaction effects did not show significant difference ($P > 0.05$) on number of pods per plant of haricot bean (Appendix Table 7). Haricot bean sown with BH

546 obtained maximum (8.34) pods per plant while haricot bean intercropped with BH 661 recoded the lower (7.23) pods per plant. With respect to haricot bean varietal effects, the maximum (8.64) and minimum (6.93) pod numbers per plant were obtained in Batu and Lehode varieties, respectively. Haricot bean sown simultaneously with maize showed the greatest (17.23) pods per plant whereas, the lowest (2.25) was observed in haricot beans sown four weeks after maize sowing (Table 4.12).

Table 4.12. Main effect of maize varieties, haricot varieties and its time of sowing on number of pods per plant of haricot bean in maize-haricot bean intercropping system

Treatments	Haricot bean characters Number of pods per plant of haricot bean
Maize varieties	
BH 546	8.34[a]
BH 661	7.23 [b]
LSD (0.05)	**0.62***
Haricot bean varieties	
Batu	8.64[a]
Lehode	6.93[b]
LSD (0.05)	**0.62***
Sowing Time	
Simultaneous	17.23[a]
Two weeks later	3.87[b]
Four weeks later	2.25 [c]
LSD (0.05)	**0.76*****
SE±	**0.89**
CV	**6.52**

Note: *Means with similar letters in the same column are not significantly different at P<0.05 LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; NS= non-significant; **= highly significant; ***= very highly significant; cm centimetre*

A variation in number of pods per plant of haricot bean varieties might be the inherent genetic characteristic of component crops varieties. Delaying introduction of the haricot bean in already established maize stand resulted in progressive decline the number of pods per plant of haricot bean which could be arise from the level of shading and inter specific competition during grain filling stage of the late seeded pulses. With regards to effect of haricot bean varieties, concomitant findings were reported by Teshome Gutu *et al*. (2015) who stated that the highest number of pods per plant (45) was obtained for variety Boshe while variety Ethio-Yugoslavia had the lowest (31.89).

The comparison result between sole and intercropped haricot bean revealed that there was highly significant ($P < 0.01$) difference in number of pods per plant of haricot bean. Hence, the maximum (21.21) and minimum (6.93) pod numbers per plant were obtained on sole cropped Batu and intercropped Lehode, respectively (Table 4.13). The decrease in number of pods per plant could be due to the competition effect of maize varieties in the intercropping system. Carruthers *et al.* (2000) described this condition to the reduction of photosynthesis due to shading of associated crops to a level that the legume plants compensated by decreasing the amount of assimilate allocation to grain production. This also corresponds with the results of Ghosh (2004), who reported pod yield of groundnut were lower in groundnut-cereal (maize, sorghum, and pearl millet) intercropped than in monoculture. Furthermore, Demissie Alemayehu *et al*. (2018) reported that the highest number of pods per plant was obtained from sole Ibbado haricot bean variety while intercropping system had the lowest.

Table 4.13. Effect of sole planting and intercropping treatments on plant height (cm), number of pods per plant and number of seed per pod of haricot bean

Treatments	Haricot bean characters		
	Plant height	Number of pods per plant	Number of seed per pod
Sole Batu	70.80^{a}	21.21^{a}	4.75^{a}
Sole Lehode	67.20^{b}	13.93^{b}	4.06^{a}
Intercropped Batu	59.42^{c}	9.48^{bc}	3.20^{b}
Intercropped Lehode	55.59^{d}	6.93^{c}	2.70^{b}
LSD (P<0.05)	**3.09***	**4.44****	**0.86****
SE±	**1.05**	**1.53**	**0.29**
CV (%)	**8.08**	**9.71**	**8.92**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; *=significant; **= highly significant; cm= centimetre.*

Number of seeds per pod

The analysis of variance revealed that all the main effects as well as the three-way interaction effects of maize varieties, haricot bean varieties and time of sowing highly significantly ($P < 0.01$) affects number of seeds per plant of haricot bean (Appendix Table 7). Accordingly, variety Batu simultaneously sown with BH 546 provide the maximum seed numbers per pod (4.64) and the lowest (0.73) was observed in Lehode variety sown four weeks after BH 661 sowing (Table 4.14). This might be result from differences in genetic makeup of component crops varieties as well as delayed planting of legumes in well-established cereal forming closed canopy restricting arrival of direct sunlight that intern reduced photosynthesis.

Table 4.14. Three-way interaction effect of maize varieties, haricot bean varieties and time of sowing of haricot bean on number of seeds per pod of haricot bean

Maize varieties	Haricot bean character		
	Haricot bean varieties	Time of sowing	Number of seeds per pod of haricot bean
BH 546	Batu	Simultaneous	4.64^{a}
		Two weeks later	3.97^{b}
		Four weeks later	1.48^{de}
	Lehode	Simultaneous	4.49^{ab}
		Two weeks later	2.64^{c}
		Four weeks later	1.22^{ef}
BH 661	Batu	Simultaneous	4.35^{ab}
		Two weeks later	2.02^{d}
		Four weeks later	1.84^{d}
	Lehode	Simultaneous	4.17^{ab}
		Two weeks later	2.93^{c}
		Four weeks later	0.73^{f}
LSD			**0.61****
SE±			**0.21**
CV			**11.21**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; ***= very highly significant*

This finding agrees with that of Adipala *et al*. (2002) and Saban *et al*. (2007) who notified that delaying introduction of legumes in already established maize stand, resulted decline of number of seeds per pod of pulses. With regard to effect of varieties, similar finding has been reported by Biruk Tesfaye (2007) differences in number of seeds per pods of intercrops due to varietal variations. Likewise, Solomon Kebebew *et al*. (2014) analysed the significant effect of soybean varieties on number of pods per plant which might be resulted from varietal differences and the ability of individual variety to exploit the available resources like solar radiation, soil moisture and nutrients.

The comparison result between sole and intercropped haricot bean indicated that there was highly significant ($P < 0.01$) difference in number of seeds per pod of haricot bean. The highest seed numbers per pod (4.75 and 4.06) was registered in sole cropped Batu and Lehode, respectively while the lowest (3.20 and 2.70) was recorded in intercropped Batu and Lehode, respectively (Table 4.13). This could be due to high level of resource competition between component crops in an intercropping system than monocrops having full access of resources. This result was in conformity with the result of Chui and Richard (2003) who reported where intercropping reduced soybean biological yield by 87 % when compared with sole cropping, principally because of reduced plant growth and photosynthetic assimilation (Kipkemoi *et al.,* 2003). Moreover, Demissie Alemayehu *et al*. (2018) observed significant effect on number of seed per pod in cropping system in maize-bean intercropping.

Grain yield

The analysis of variance revealed that main effect of sowing time was very highly significantly ($P < 0.001$) and maize varieties and haricot bean varieties were significantly ($P < 0.05$) affected grain yield of haricot bean. The remaining two-way and three-way interaction effects did not show significant influence on grain yield of haricot bean (Appendix Table 8). Following this the highest (1836.34 kg/ha) and the lowest (460.94 kg/ha) grain yields were obtained in simultaneously sown haricot beans and haricot beans sown four weeks after maize sowing, respectively. With regard to time of introduction Demissie Alemayehu *et al*. (2017) explained seed yield of the three varieties of common bean in intercropping generally exhibited an extreme decline as their planting was delayed after maize, which implies the presence of severe competition for resource as maize crop becomes well established. Likewise, Saban *et al*, (2007) examined that simultaneous intercropping of common bean varieties yielded the highest grain yield as compared to the subsequent seeding.

With respect to effect of maize varieties the higher (1266.47 kg/ha) and lower (1124.87 kg/ha) grain yields were obtained in haricot beans intercropped with BH 546 and BH 661 varieties, respectively (Table 4.15). From the general decrease of intercropped legumes yield Hauggaard Nielsen *et al*. (2001) also examined that maize has a competitive advantage because its roots occupy both shallow and deeper soil layers and have a superior ability to recover soil mineral N, whereas root systems of legumes are smaller and confined to the upper soil layer.

On the other way, haricot bean variety Batu recorded the higher (1247.34 kg/ha) grain yield while variety Lehode was the lower (1144.01 kg/ha) (Table 4.15). The variation in yield of haricot bean due to varietal effect and time of introduction might be resulted from the nature of below ground and above ground resource use efficiency of the varieties and poor stand establishment of delayed introductions tend them reduced assimilate productions. In agreement with this result, Zerihun Abebe (2011) notified that intercropping of Didesa variety with maize resulted in significant yield increase over Boshe and this increase in yield was about 57.7 %.

The analysis of variance for cropping system showed that there was highly significant ($P < 0.01$) difference in grain yield of haricot bean (Table 4.18). So that the highest grain yield was observed in sole cropped Batu and Lehode (2241.2 and 2120.8kg/ha), respectively where the lowest (1294.03 and 1144 kg/ha) was recorded in intercropped Batu and Lehode, respectively. Concomitant reports were stated by Muoneke *et al*. (2007) reported yield reduction in soybean inter cropped with maize and sorghum and attributed the yield depression to inter specific competition and the depressive effect of the cereals. Likewise, a range of 21 % to 75 % yield reduction of the intercropped soybean due to shading effect was reported by (Mudita *et al*., 2008). Moreover, Ghosh (2004) examined that because of the difference in canopy height of soybean and sorghum, the two species not only competed for nutrient and water but also for light.

Table 15. Main effect of maize varieties, haricot varieties and its time of sowing on grain yield (kg/ha) of the haricot bean in maize-haricot bean intercropping system

	Haricot bean characters
Treatments	Grain yield
Maize varieties	
BH 546	1266.47[a]
BH 661	1124.87[b]
LSD (0.05)	**63.18***
Haricot bean varieties	
Batu	1247.34[a]
Lehode	1144.01[b]
LSD (0.05)	**63.18***
Sowing Time	
Simultaneous	1836.34[a]
Two weeks later	1289.75[b]
Four weeks later	460.94[c]
LSD (0.05)	**77.38*****
SE±	**52.77**
CV	**7.69**

Note: *LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; rep= replication; NS= non-significant; *=significant; ***= very highly significant; kg/ha= kilo gram per hectare.*

Above ground biomass yield

The analysis of variance showed that main effect of sowing time and interaction effect of maize varieties with sowing time and interaction effect of haricot bean varieties with sowing time highly significantly ($P < 0.001$) and significantly ($P < 0.05$) affects above ground biomass yield of haricot bean, respectively. On the other hand, main effect of maize varieties and haricot bean varieties did not significantly ($P > 0.05$) affect above ground biomass yield of haricot bean (Appendix Table 8). Haricot bean simultaneously sown with BH 546, simultaneously sown with BH 661 and intercropped two weeks later with BH 661 showed greater above ground biomass yield with a value of (3494.8 kg/ha, 3418.8 kg/ha and 3405.4 kg/ha), respectively. Whereas, the lower (1453.1 kg/ha and 1880.02) was occurred in haricot bean sown four weeks after BH 661 and BH 546 sowing, respectively in two-way interaction effect of maize varieties and sowing time (Table 4.16). In line with this result Abuhay Takele and Jibril Mohammed (2016) notified that highest biomass weight (kg/ha) of haricot bean was produced when haricot bean was planted simultaneously with maize and significantly decreased with delayed time of intercropping haricot bean.

Table 4.16. Two-way interaction effect of maize varieties with time of sowing on above ground biomass yield (kg/ha) of haricot bean

Maize varieties	Haricot bean character	
	Time of sowing	Above ground biomass yield
BH 546	Simultaneous	3494.8^{a}
	Two weeks later	2844.5^{b}
	Four weeks later	1880.2^{c}
BH 661	Simultaneous	3418.8^{a}
	Two weeks later	3405.4^{a}
	Four weeks later	1453.1^{c}
LSD		**466.41****
SE±		**227.69**
CV		**11.34**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; **= highly significant; kg/ha= kilo gram per hectare.*

In the same way for the interaction effect of haricot bean varieties with that of time of sowing the maximum (3546.7 kg/ ha, 3449.4 kg/ ha and 3366.9 kg/ ha) above ground biomass yield were recorded on simultaneously sown Lehode variety, variety Batu intercropped two weeks later and variety Batu simultaneously intercropped, respectively. While the minimum (1666.7 kg/ha) above ground biomass yield were recorded on both varieties sown four weeks after maize sowing (Table 4.17). This significant variation in above ground biomass yield with time of sowing and varietal differences might be because of increased canopy closure by the main crop resulting poor vegetative and reproductive growth and nature of varietal genetic characteristics. With regard to haricot bean variety, similar findings were reported by Biruk Tesfaye (2007) observed significant difference on aboveground dry biomass production due to main effect of haricot bean variety.

Table 4.17. Two-way interaction effect of haricot bean varieties with time of sowing on above ground biomass yield (kg/ha) of haricot bean

Haricot bean varieties	Haricot bean character	
	Time of sowing	Above ground biomass yield
Batu	Simultaneous	3366.9[a]
	Two weeks later	3449.4[a]
	Four weeks later	1666.7[c]
Lehode	Simultaneous	3546.7[a]
	Two weeks later	2800.6[b]
	Four weeks later	1666.7[c]
LSD		**474.3***
SE±		**231.54**
CV		**9.58**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; **= highly significant; kg/ha= kilo gram per hectare.*

The analysis of variance for cropping system showed that there was highly significant ($P < 0.01$) difference in above ground biomass yield of haricot bean. Hence, the highest above ground biomass yield was observed in sole cropped Lehode and Batu (4140.3 and 3980.7 kg/ha), respectively whereas the lowest (2810.33 and 2671.33 kg/ha) was recorded in intercropped Batu and Lehode (Table 4.18). This result was in conformity with the result reported by Chui and Shibles (2003) where intercropping reduced soybean biological yield by 87 % when compared with sole cropping, principally because of reduced plant growth and photosynthetic assimilation (Kipkemoi *et al*., 2003).

Table 4.18. Effect of sole planting and intercropping treatments on grain yield (kg/ha), above ground biomass yield (kg/ha), harvest index and hundred seed weight (g) of haricot bean

Treatments	Haricot bean characters			
	Grain yield	ABYH	Harvest index	Hundred kernel weight
Sole Batu	2241.2[a]	3980.7[a]	0.59[a]	55.00[a]
Sole Lehode	2120.8[a]	4140.3[a]	0.51[ab]	44.00[bc]
Intercropped Batu	1294.03[b]	2810.33[b]	0.43[b]	48.11[b]
Intercropped Lehode	1144.00[b]	2671.33[b]	0.41[b]	39.50[c]
LSD (P<0.05)	**259.07****	**504.87****	**0.1****	**6.46****
SE±	**89.12**	**173.67**	**0.004**	**2.22**
CV (%)	**9.37**	**10.26**	**7.45**	**8.63**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; ABYH= above ground biomass yield; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; **= highly significant; kg/ha= kilo gram per hectare; g= gram.*

Harvest index

The analysis of variance showed that both main effect of maize varieties and sowing time and three-way interaction effect highly significantly ($P < 0.01$) affected the harvest index of haricot bean. On the other hand, main effect of haricot bean varieties and interaction effect of maize varieties with haricot bean varieties did not significantly ($P > 0.05$) affect harvest index of haricot bean (Appendix Table 8). Following this the height harvest index (0.58) was observed in simultaneously sown Batu with maize variety BH 546 while the lowest (0.23) was recorded in variety Lehode sown four weeks after BH 546 sowing (Table 4.19). This might be due to better stand establishment and growth of legumes in the early stages when simultaneously introduced with cereals as it gives efficient resource utilization and assimilates production capability. This result disagrees with the finding of Carruthers *et al*. (2000), who reported that simultaneously seeding of soybean with maize resulted in decreased harvest index.

Table 4.19. Three-way interaction effect of maize varieties, haricot bean varieties and time of sowing of haricot bean on harvest index of haricot bean

Maize varieties	Haricot bean character		
	Haricot bean varieties	Time of sowing	Harvest index
BH 546	Batu	Simultaneous	0.59[a]
		Two weeks later	0.42[c]
		Four weeks later	0.31[de]
	Lehode	Simultaneous	0.51[ab]
		Two weeks later	0.57[a]
		Four weeks later	0.23[f]
BH 661	Batu	Simultaneous	0.54[ab]
		Two weeks later	0.36[cd]
		Four weeks later	0.27[fe]
	Lehode	Simultaneous	0.50[b]
		Two weeks later	0.35[cd]
		Four weeks later	0.27[fe]
LSD			**0.072****
SE±			**0.0018**
CV			**10.34**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; **= highly significant*

The comparison result between sole and intercropped haricot bean showed that there was highly significant ($P < 0.01$) difference in harvest index of haricot bean. The height harvest index (0.59) was observed in sole cropped Batu while the lowest (0.43 and 0.41) was recorded in both intercropped varieties of Batu and Lehode, respectively (Table 4.18). This could be due to ample resource and absence of interspecific competition in mono culture crops.

Hundred kernels weight

The analysis of variance showed that hundred kernels weight of haricot bean was very highly significantly ($P < 0.001$) affected by main effect of haricot bean varieties and time of sowing while significantly ($P < 0.05$) affected by interaction effect of maize varieties with sowing date. On the other hand, main effect of maize varieties and the rest interaction effects din not significantly (P > 0.05) affect hundred kernels weight of haricot bean (Appendix Table 8). Accordingly, variety Batu recorded the higher (47.44) hundred kernel weight while the lower was recorded in variety Lehode (39.5) (Table 4.20).

Table 4.20. Main effect of haricot bean varieties and time of sowing of haricot bean on hundred kernel weight (g) of the haricot bean in maize-haricot bean intercropping system

Treatments	Haricot bean parameter
	Hundred kernel weight
Haricot bean varieties	
Batu	47.44[a]
Lehode	39.50[b]
LSD (0.05)	**2.53*** **
LSD (0.05)	**3.09*** **
SE±	**2.11**
CV	**8.4**

Note: *LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; NS= non-significant; ***= very highly significant; g=gram.*

In the two-way interactions the highest hundred kernels weight (47.83 g, 46.50 g and 45.66 g) were observed in simultaneously sown haricot bean with variety BH 546 and BH 661 intercropped two weeks later with BH 546, respectively. On the other hand, the lowest kernels weight (35.33 g and 43.66 g) were observed in haricot beans sown four weeks and two weeks after BH 661 sowing, respectively (Table 4.21). In agreement with this result, Jibril Temesgen *et al.* (2015) reported that a significant difference in hundred seed weight of common bean was observed in maize-bean intercropping due to varietal difference.

The analysis of variance for cropping system showed that there was highly significant (P < 0.01) difference in hundred kernels weight of haricot bean (Table 4.18). Hence the highest hundred kernels weight was observed in sole cropped Batu (55 g) where the lowest (48.11 and 39.50 g) was recorded in both intercropped varieties of Batu and Lehode, respectively. In line with this result Undies *et al*. (2012) reported that the sole crop produced significantly higher 100-grain weight than any of the intercropped arrangements.

Table 4.21. Two-way interaction effect of maize varieties and time of sowing of haricot bean on hundred kernel weight (g) of the haricot bean in maize-haricot bean intercropping system

	Haricot bean character	
Maize varieties	Time of sowing	Hundred kernel weight
	Simultaneous	47.83^{a}
BH 546	Two weeks later	45.66^{a}
	Four weeks later	41.83^{ab}
	Simultaneous	46.50^{a}
HB 661	Two weeks later	43.66^{b}
	Four weeks later	35.33^{b}
LSD (0.05)		**6.9***
SE±		**3.67**
CV		**11.42**

Note: *Means with similar letters in the same column are not significantly different at P<0.05; LSD= least significance difference; SE±= standard error of mean; CV= coefficient of variation; *= significant; g=gram*

4.3 Land Use Efficiency in Maize-Haricot Bean Intercropping System

4.3.1 Land equivalent ratio (LER)

The result revealed that all values of total land equivalent ratio (LER) in different intercropping systems were found to be greater than one indicating higher land use efficiency of intercropping systems over the respective mono cropping systems. The highest total LER value (1.61) was recorded in variety BH 661 simultaneously intercropped with Batu, where BH 661 and Batu achieved 81 % and 80 % of their sole yields, respectively indicating higher biological yield and economic efficiency (Table 22). It indicates that 66 % yield advantage was obtained because of intercropping of component crops or additional 0.66 hectare was required to obtain equivalent yield in separate cultures of component crops.

On the other hand, variety Lehode intercropped four weeks after sowing of maize variety BH 546 had recorded the lowest (1.06) LER value (Table 4.22). This is to mean that only 0.06 % yield advantage was obtained as time of haricot bean sowing becomes late. The reduced LER value might be resulted from lower varietal yielding potential of maize and minimal biological yield of legumes as they were introduced lately because of extensive shading effect of well-established base crop (maize). Concomitant results were stated by Demissie Alemayehu *et al*. (2018) who notified that cropping system showed significant effect on LER where of intercropping was (1.17) which showed 17 % yield advantage and efficient land use efficiency by intercropping as compared to sole cropping might be resulted from better utilization of land, light, nutrient and water. Moreover, Ashenafi Nigussie (2016) stated that intercropping of maize with haricot bean increased land use efficiency and gave higher total yields compared to growing either species in separate cultures.

Table 4.22. Effects of maize verities, haricot bean varieties and time of sowing of haricot bean on partial LER, total LER, ATER and monetary advantage index of component crops

Treatments	Partial LER of HB	Partial LER of maize	Total LER	ATER	MAI
Sole BH 546	-	1.00	1.00	1.00	0
S0le BH 661	-	1.00	1.00	1.00	0
Sole Batu	1.00	-	1.00	1.00	0
Sole Lehode	1.00	-	1.00	1.00	0
BH546+Batu+ Simultaneous sowing	0.65	0.84	1.49	1.22	32491.13
BH546+Lehode+Two weeks AMS	0.62	0.88	1.50	1.24	27844.54
BH546+Batu+Four weeks AMS	0.28	0.94	1.22	1.10	13713.11
BH546+Lehode +Simultaneous	0.85	0.73	1.58	1.22	30912.53
BH546+Batu+ Two weeks AMS	0.64	0.81	1.45	1.18	26688.59
BH546+Lehode+ Four weeks AMS	0.20	0.87	1.08	0.99	3798.80
BH661+Batu +Simultaneous sowing	0.80	0.81	1.61	1.27	42549.47
BH661+Lehode+ Two-week AMS	0.54	0.87	1.41	1.18	28269.20
BH661+Batu +Four weeks AMS	0.17	0.89	1.06	0.99	5355.28
BH661+Lehode+Simultaneous sowing	0.83	0.73	1.56	1.21	33667.00
BH6661+Batu+ Two weeks AMS	0.69	0.81	1.50	1.21	33707.51
BH661+Lehode+ Four weeks AMS	0.20	0.89	1.09	1.01	6822.37

Note: *LER= land equivalent ratio; HB= haricot bean; ATER= area time land equivalent ratio; MAI= Monetary Advantage Index, S= sowing; AMS= After Maize Sowing.*

4.3.2 Area time land equivalent ratio (ATER)

The result for area time land equivalent ratio values were found greater than one in most intercropping systems with the exception of treatments with third time sowing of haricot beans. Thus, Maize variety B661 simultaneously intercropped with haricot bean variety of Batu showed higher ATER value (1.27) which means about 27 % yield advantage over that of separate cultures of component crops (Table 4.22). The higher ATER values from simultaneous intercropping of component crops might be resulted from higher biological yield of legumes as compared to later introduced legumes, which indicates efficient use of resources over time. In line with this result Maitra *et al.* (2021) revealed the advantageous ATER values in different intercropping systems particularly maize-black cowpea and maize-soybean intercropping systems. Moreover, Reddy *et al*. (1994) explained that intercropping systems can actually give more efficient total resource exploitation and greater overall production than sole crops (compatible intercrops).

4.4 Profitability of Cropping System

4.4.1 Monetary advantage index (MAI)

Accordingly, all of the treatments had positive values of MAI. The positive monetary advantage index values showed the economic feasibility of intercropping systems as compared to sole cropping. Thus, variety Batu simultaneously intercropped with variety BH 661 and variety Batu intercropped with BH 661 after two weeks had the highest value of MAI (42549.47, 33707.51), respectively. The lower value of MAI was recorded in variety Lehode intercropped four weeks after BH 546 sowing and variety Batu intercropped four weeks after BH 661 sowing with the value of (3798.80 & 5355.28), respectively (Table 4.22).

This lower MAI values could be due to lowest LER values of respective treatments. Concomitant results were reported by Abuhay Takele and Jibril Mohammed (2016) indicated that intercropping of haricot bean to the maize system was advantageous than sole maize and/or sole haricot bean cropping and among the time of intercropping treatments, simultaneous planting of haricot bean was more advantageous than delayed intercropping haricot bean to the maize system. Likewise, Islam *et al*. (2016) revealed that yield and economic advantages in turmeric-sesame intercropping at all the combination were observed over their sole cropping. Moreover, Kinde Lamessa *et al*. (2015) results are reported that intercropping of soybean and cowpea with sorghum was more advantageous than sole cropping sorghum.

4.4.3 Partial budget analysis

The partial budget analysis was done for the two-way interaction effects of haricot bean variety with its time of sowing based on the result of stasticial data analysis.

Table 4.23 Effect of haricot bean varieties and time of sowing on production cost, incomes and net profit in maize-haricot bean intercropping system

Treatments	Cost (EB)				Incomes (EB)			Benefits (EB)	
	maize seed cost	Haricot bean seed	Labour cost	Total Variable Cost (TVC)	Income from adjusted haricot bean grain yield/ha	Income from adjusted maize grain yield/ha	Income from adjusted maize straw yield/ha	Total Gross Benefit (GB)	Net Benefit (NB)= (GB-TVC)
Sole Batu	-	2200	4200	6400	43560.00	-	-	43560.00	37160.00
Sole Lehode	-	1600	4200	5800	28800.00	-	-	28800.00	23000.00
Sole BH 546	450	-	3180	3630	-	60422.5	1408.18	61830.68	58200.68
Sole BH 661	750	-	3180	3930	-	75451.47	1802.89	77254.36	73324.36
Simultaneous sown with Batu	600	733.04	4405	5738.04	37370.52	56055.24	3159.75	96585.51	90847.47
Batu sown two weeks after maize	600	733.04	4305	5638.04	26821.48	54790.83	4059.81	85672.12	80034.08
Batu sown four weeks after maize	600	733.04	4255	5588.04	9900.00	64173.06	3469.14	77542.20	71954.16
Simultaneous sown with Lehode	600	559.44	4405	5564.44	32134.86	48431.52	4895.03	85461.41	79896.97
Lehode sown two weeks after maize	600	559.44	4305	5464.44	22047.66	59594.94	4048.63	85691.23	80226.79
Lehode sown four weeks after maize	600	559.44	4255	5414.44	7593.84	60185.43	4311.64	72090.91	66676.47

Note: *EB= Ethiopian Birr; TVC=Total Variable Cost; GB=Gross Benefit; ha=hectare*

Table 4.24 Dominance analysis of treatments

Treatments	Total Variable Cost (TVC) (EB/ha)	Net Benefit (NB) (EB/ha)	Dominance
Sole BH 546	3630.00	58200.68	
Sole BH661	3930.00	73324.36	
Lehode sown four weeks after maize	5414.44	66676.47	D
Lehode sown two weeks after maize	5464.44	80226.79	
Simultaneous sown with Lehode	5564.44	79896.97	D
Batu sown four weeks after maize	5588.04	71954.16	D
Batu sown two weeks after maize	5638.04	80034.08	D
Simultaneous sown with Batu	5738.04	90847.47	
Sole Batu	5800.00	23000.00	D
Sole Lehode	6400.00	37160.00	D

Note: *EB= Ethiopian Birr; D=Dominated; TVC=Total Variable Cost; GB=Gross Benefit; ha=hectare*

Thus, haricot bean variety Batu simultaneously intercropped with maize variety BH 661 had acceptable level of MRR with the highest net benefit (90847.47 Birr /ha) was the best economically profitable treatment and recommended for the study area (Table 4.25). Similar findings were reported by Zerihun Abebe *et al*. (2017) that the highest net benefit (38808 ETB/ha) and more marginal rate of return (MRR) could be obtained when climbing bean was intercropped simultaneously with BH661 variety of maize. On the contrary, Yusuf *et al*. (2014) reported that the highest net benefit was produced in the intercrop treatment of soybean planted 14 days after maize.

Table 4.25 Marginal rate of return (MRR %) as influenced by time of sowing of haricot bean varieties in maize-haricot bean intercropping system

Treatments	Total Variable Cost (TVC) (EB/ha)	Net Benefit (NB) (EB/ha)	MRR %
Sole BH 546	3630	58200.68	
Sole BH661	3930	73324.36	5041.2
Lehode sown two weeks after maize	5464.44	80226.79	449.83
Simultaneous sown with Batu	5738.04	90847.47	3881.83

Note: *EB= Ethiopian birr; MRR=Marginal rate of return; D=Dominated; TVC=Total Variable Cost; GB=Gross Benefit*

4.5 Competitive Ratio

Competitive ratio (CR) is only used as a measure of intercrop competition between the component crops in the system (Trydeman *et al*., 2004). As the analysis result reveals more positive values (0.72 and 0.69) were obtained in late sown varieties of haricot bean with BH 661. Thus, maize variety BH 661 was more competent than the legume component especially in treatments BH 661 intercropped with both varieties of haricot bean after four weeks. On the contrary, haricot bean variety Lehode intercropped simultaneously with BH 546 and BH 661 was more competent than cereal component (-0.12 and -0.1), respectively (Table 4.26). This could be due to reduced competition of legumes in late introductions in already well-established cereal component for essential growth resources. In line with this Zerihun Abebe *et al*. (2017) were reported similar findings that the highest positive value (0.6) was recorded when bean varieties were intercropped after 20 days of BH546 variety was planted while the next highest value was recorded when the beans were planted 20 days after BH661 was planted. At same time of bean planting with maize varieties, BH661 was significantly more aggressive over beans than BH546 and hence less yield reduction was recorded compared to the later one.

Table 4.26 Competitive ratios for maize-haricot bean variety intercrops at three sowing time of the legume component

Treatments	Partial LER of Maize	Partial LER of Haricot bean	Competitive ratio (CR) =LER of maize-LER of haricot bean
BH546+Batu+ Simultaneous sowing	0.84	0.65	0.19
BH546+Lehode+Two weeks AMS	0.88	0.62	0.26
BH546+Batu+Four weeks AMS	0.94	0.28	0.66
BH546+Lehode +Simultaneous	0.73	0.85	-0.12
BH546+Batu+ Two weeks AMS	0.81	0.64	0.17
BH546+Lehode+ Four weeks AMS	0.87	0.2	0.67
BH661+Batu +Simultaneous sowing	0.81	0.8	0.01
BH661+Lehode+ Two-week AMS	0.87	0.54	0.33
BH661+Batu +Four weeks AMS	0.89	0.17	0.72
BH661+Lehode+Simultaneous sowing	0.73	0.83	-0.1
BH6661+Batu+ Two weeks AMS	0.81	0.69	0.12
BH661+Lehode+ Four weeks AMS	0.89	0.2	0.69

Note; *LER=land equivalent ratio; CR= competitive ratio*

4.6 Correlation between Parameters of Component Crops

4.6.1 Correlation between important parameters of haricot bean

As the correlation analysis result reveals, yield attributed parameters such as; plant height (r= 0.92**), number of pod per plant (r=0.85**) and number of seed per pod (r=0.92**) was positively and very strongly correlated with grain yield of haricot bean. In the same way above ground biomass yield (r=0.65**), harvest index (r=0.79**) and hundred kernels weight (r=0.62**) also positively and strongly related with grain yield of haricot bean. But grain yield was positively and moderately related with days to 90% physiological maturity (r=0.45**).

Above ground biomass yield of haricot bean also positively and very strongly related with grain yield (r=0.86**) and harvest index (r=0.89**) .On the other hand, it was positively and strongly related with plant height (r=0.79**), number of pods per plant (r=0.65**), number of seed per pod (r=0.79**) and hundred kernels weight (r=0.86**). Similarly, haricot bean above ground biomass yield was positively and weakly related days to 90% physiological maturity (r=0.39*) (Table 4.26). This significant relation analysis result confirmed us most of yield attributed parameters in the intercropped systems were associated each other in a linear manner in both grain yield and above ground biomass yield haricot bean (Table 4.27). In conformity with this result Molla Abate and Getachew Alemayehu (2020) reported that most important agronomic parameters were positively and strongly correlated with grain and above ground biomass yield of legume components in maize-legume intercropping. Moreover, Xingcai *et al*. (2020) reported positive and significant association of soy bean grain yield with above ground biomass yield and plant height in maize-haricot bean intercropping.

Table 4.27 Correlation between agronomic characters of haricot bean as affected by maize varieties, haricot bean varieties and planting time of haricot bean in an intercropping system

	DFFH	DNM	PHH	NPPH	NSPH	GYH	BYH	HIH	HSWH
DFFH	1								
DNM	0.77**	1							
PHH	0.56**	0.38*	1						
NPPH	0.54**	0.53**	0.84**	1					
NSPH	0.61**	0.49**	0.93**	0.82**	1				
GYH	**0.61****	**0.45****	**0.92****	**0.85****	**0.92****	1			
BYH	**0.50****	**0.39****	**0.79****	**0.65****	**0.79****	**0.86****	1		
HIH	0.55**	0.36**	0.78**	0.75**	**0.79****	**0.89****	0.58**	1	
HSWH	0.15NS	0.07NS	0.69**	0.57**	**0.62****	**0.64****	0.56**	0.56**	1

Note: *DFFM=Days to 50% flowering; DMM=days to 90% maturity; PHH=plant height; NPPH=number of cobs per plant; NSPH=number of seed per plant; GYH= Grain yield; ABYH= Aboveground biomass yield; HIH= harvest index; TKH= Thousand kernel weight.*

4.6.2 Correlation between important parameters of maize

The correlation analysis result indicated that, yield attributed parameters such as; days to 50% tasseling (r=0.74**), 90% physiological maturity (r=0.73**), plant height (r= 0.77**), number of leaves per plant (0.68**) and number of cobs per plant (r=0.73**) was positively and strongly correlated with grain yield of maize. Whereas it was related with ear diameter positively and moderately (r=0.57**). But there was no significant correlation of grain yield with above ground biomass yield, harvest index and hundred kernels weight of maize. This significant relation analysis result indicates us most of parameters in the intercropped systems were associated each other in a linear manner in both grain and above ground biomass yield of maize (4.28).

With regard to above ground biomass yield, the correlation analysis result revealed that it was positively and weakly correlated with yield attributed parameter of maize; number of cobs per plant (r=0.35*), ear diameter (r=0.38 *) and harvest index (r=0.36*). The rest yield attributed parameters were not a significant relation with above ground biomass yield. This significant relation analysis result ascertained us the parameters in the intercropped systems were associated each other in a linear manner in terms of maize component (4.27).

Table 4.28 Correlation between agronomic characters of maize as affected by maize varieties, haricot bean varieties and planting time in an intercropping system

	DFTM	DMM	PHM	NLPM	NCPM	EDM	ELM	GYM	BYM	HI	HSW
DFTM	1										
DMM	**0.98****	1									
PHM	0.99**	0.99**	1								
NLPM	0.45**	0.39**	0.44**	1							
NCPM	0.43**	0.43**	0.47**	0.53**	1						
EDM	0.30NS	0.31NS	0.36**	0.47**	0.51**	1					
ELM	0.39**	0.35*	0.34**	0.13NS	0.07NS	0.13*	1				
GYM	**0.74****	**0.73****	**0.77****	**0.68****	**0.73****	**0.57****	**0.24NS**	1			
BYM	**0.17NS**	**0.09NS**	**0.13NS**	**0.15NS**	**0.35***	**0.16NS**	**0.38***	**0.09NS**	1		
HI	0.17NS	0.24NS	0.22NS	0.14NS	0.33*	0.14NS	**-0.13NS**	**0.36***	-0.87**	1	
HSW	-0.07NS	-0.08NS	-0.07NS	0.21NS	0.01*	0.42**	**0.27NS**	**0.08NS**	0.40*	-0.32**	1

Note: *DFTM=Days to 50% tasselling; DMM=days to 90% maturity; PHM=plant height; NLPM=number of leaves per plant; NCPM=number of cobs per plant of maize; EDM= Ear diameter; GYM= Grain yield; ABYM= Aboveground biomass yield; HIM= harvest index; TKW= Thousand kernel weight.*

Chapter 5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The result of this study revealed that main effect of maize variety significantly affects the phenological parameters of maize; hence variety BH 546 reaches to 50 % tasselling and 90 % physiological maturity (9.72 days and 20.94 days) earlier than variety BH 661 respectively. Similarly, cob numbers per plant, ear length, ear diameter and grain yield were influenced by times of sowing and maize varieties. Accordingly, the higher yield advantage was obtained in maize intercropped with variety Batu for weeks later with a value of 7817.7 kg/ha. Probably this yield advantage could be resulted from weak stand establishment and least competition from late introduced legumes and the inherent yielding potential and agro ecological adaptation of the varieties.

With regard to the result of haricot bean components, simultaneous intercropping of haricot bean variety with maize resulted extended days to flowering and maturity compared to the remaining times of intercropping. Likewise, taller plant heights, increased pod numbers per plant, number of seeds per pod and better yields were observed in main effects of haricot bean variety Batu, simultaneous intercropped haricot bean and the legume intercropped with variety BH 546; whereas the delayed time of plantings and intercropping with BH 661 drastically decrease both growth and yield parameters of haricot bean. This might be resulted from shading effect of different varieties of maize and greater competition for growth resources from well-established main crop.

Cropping system also showed significant influence on most parameters of component crops in which sole cropped treatments usually obtained greater growth and yield advantages. With respect to land use efficiency analysis results simultaneously intercropped variety Batu with BH 661 recorded the highest LER and ATER with a magnitude of 1.61 and 1.27, respectively. Similarly, partial budget analysis results revealed that the most profitable treatment was obtained in BH 661 simultaneously intercropped with Batu with a value 90847.47 Ethiopian Birr per hectare.

5.2 Recommendations

Up to date more research findings are not available in the concern of varietal effect and time of introduction in maize-haricot bean intercropping system in the study area; so, it needs further research on maize and haricot bean cultivars for better intercropping combination that can maximize production. Further investigation on the role of cereal-legume intercropping in nutrient enhancement (especially nitrogen) in related with N-fixation should be studied. Finally, even though it is difficult to conclude and deliver valuable recommendation in one-year experiment at a single experimental site, haricot bean variety simultaneously intercropped with BH 661 was the ideal varietal combination with right time of sowing obtained higher economic advantages for the study area.

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APPENDIX TABLES

Appendix Table 1. Analysis of variance (ANOVA) for days to 50 % tasselling and days to 90 % maturity of intercropped maize as affected by maize varieties, haricot bean varieties and time of sowing

Source of variation	Mean squares		
	Maize characters		
	Degrees of freedom	DFTM	DMM
Replication	2	0.08NS	0.00001NS
Maize variety	1	850.69***	3948.02***
Haricot bean variety	1	0.25NS	0.25NS
Sowing date	2	0.75NS	3.08NS
Mv*Hv	1	0.69NS	0.69NS
Mv*sd	2	0.03NS	0.36NS
Hv*sd	2	0.08NS	0.58NS
Mv*Hv*sd	2	0.36NS	0.19NS
Error	22	0.56	1.15
Corrected total	35		

Note: *ANOVA= analysis of variance; DFTM= days to fifty percent tasselling; DMM= days to ninety percent maturity; NS= non-significant; ***= very highly significant*

Appendix Table 2. Analysis of variance (ANOVA) for plant height, number of leaves per plant, number of cobs per plant, ear diameter and ear length of intercropped maize as affected by maize varieties, haricot bean varieties and time of sowing

Source of variation	Degrees of freedom	Mean squares				
		Maize characters				
		PHM	NLPM	NCPM	EDM	ELM
Replication	2	0.00001NS	0.0019NS	0.03NS	0.018*	6.53***
Maize variety	1	8.52***	2.66***	0.17***	0.83***	5.06**
Haricot bean variety	1	0.0002NS	0.18NS	0.0025	0.32***	4.91**
Sowing date	2	0.0051***	2.97***	0.11***	0.05***	0.04NS
Mv*Hv	1	0.00001NS	0.017NS	0.013NS	0.0004NS	0.78NS
Mv*sd	2	0.0002NS	0.25NS	0.005NS	0.0002NS	1.51NS
Hv*sd	2	0.001NS	0.02NS	0.03NS	0.058***	0.97NS
Mv*Hv*sd	2	0.0001NS	0.26NS	0.005NS	0.017*	0.35NS
Error	22	0.0002	0.22	0.009	0.004	0.57
Corrected total	35					

Note: *ANOVA= analysis of variance; PHM= plant height; NLPM= number of leaves per plant; NCPM= number of cobs per plant; EDM= ear diameter; ELM= ear length of maize; rep= replication; NS= non-significant; *= significant; **= highly significant; ***= very highly significant.*

Appendix Table 3. Analysis of variance (ANOVA) for grain yield, above ground biomass yield, harvest index and hundred kernel weight of intercropped maize as affected by maize varieties, haricot bean varieties and time of sowing

Source of variation	Degrees of freedom	Mean squares			
		Maize characters			
		GYM	ABYM	HI	HKW
Replication	2	862470.70**	72892601.4*	0.03NS	18.86*
Maize variety	1	20537573.79***	8148598.4NS	0.036NS	1.00NS
Haricot bean variety	1	706277.76*	12923485.8NS	0.008NS	5.44NS
Sowing date	2	4513522.88***	1649120.6NS	0.008NS	4.19NS
Mv*Hv	1	5378.27NS	60153286.8NS	0.05NS	0.0001NS
Mv*sd	2	279597.64NS	6668020.3NS	0.014NS	8.08NS
Hv*sd	2	1866843.86***	2296101.3NS	0.011NS	3.02NS
Mv*Hv*sd	2	17290.94NS	13795297.9NS	0.013NS	3.25NS
Error	22	95020.18	19624995.4	0.023	3.83
Corrected total	35				

Note: *ANOVA= analysis of variance; GYM=grain yield; ABYM= above ground biomass yield; HI= harvest index; HKW= hundred kernel weight; NS= non-significant; *= significant; **= highly significant; ***= very highly significant*

Appendix Table 4. Analysis of variance (ANOVA) for days to 50 % tasselling, days to 90 % maturity, plant height, number of leaves per plant, number of cobs per plant and ear diameter of sole and intercropped treatments of maize

Source of variation	Degrees of freedom	Mean squares					
		Maize characters					
		DFTM	DMM	PHM	NLPM	NCPM	EDM
Replication	2	0.16NS	0.02NS	0.000073NS	0.024NS	0.01NS	0.02*
Treatments	13	76.81**	354.32**	0.76*	1.07*	0.04**	0.06**
Error	26	0.57	1.07	0.00012	0.22	0.01	0.004
Corrected total	41						

Note: *ANOVA= analysis of variance; DFTM= days to fifty percent tasselling; DMM= days to maturity ninety percent maturity; PHM= plant height; NLPM= number of leaves per plant; NCPM= number of cobs per plant; EDM= ear diameter; *=significant; **= highly significant.*

Appendix Table 5. Analysis of variance (ANOVA) for ear length, grain yield, above ground biomass yield, harvest index and hundred kernel weight of sole and intercropped treatments of maize

Source of variation	Degrees of freedom	Mean squares				
		Maize characters				
		ELM	GYM	ABYM	HI	HKW
Replication	2	5.81*	596203.56*	59706784.7*	0.026NS	21.02*
Treatments	13	1.29NS	3688960.43**	14130357.0NS	0.03NS	3.47NS
Error	26	0.74	110638.41	15735127.8	0.02	4.35
Corrected total	41					

Note: *ANOVA= analysis of variance; ELM= ear length; GYM=grain yield; ABYM= above ground biomass yield; HI= harvest index; HKW= hundred kernel weight; NS= non-significant; *= significant; **= highly significant*

Appendix Table 6. Analysis of variance (ANOVA) for days to 50 % flowering and days 90 % maturity of intercropped haricot bean as affected by maize varieties, haricot bean varieties and time of sowing

Source of variation	Mean squares		
	Haricot bean characters		
	Degrees of freedom	DFH	DMH
Replication	2	0.19NS	29.77NS
Maize variety	1	53.77*	30.25NS
Haricot bean variety	1	0.11NS	8.02NS
Sowing date	2	38.52**	128.52*
Mv*Hv	1	0.11NS	20.25NS
Mv*sd	2	1.36NS	2.08NS
Hv*sd	2	0.19NS	65.86NS
Mv*Hv*sd	2	0.03NS	39.08NS
Error	22	0.77	27.80
Corrected total	35		

Note: *ANOVA= analysis of variance; DFH= days to fifty percent flowering; DMH= days to ninety percent maturity; NS= non-significant; *= significant; **= highly significant.*

Appendix Table 7. Analysis of variance (ANOVA) for plant height, number of pods per plant and number of seeds per pod of intercropped haricot bean as affected by maize varieties, haricot bean varieties and time of sowing of haricot bean

Source of variation	Degrees of freedom	Mean squares Haricot bean characters		
		PHH	NPPH	NSPH
Replication	2	0.24NS	0.89NS	0.18NS
Maize variety	1	5.14*	11.00*	0.83**
Haricot bean variety	1	108.16*	26.18*	1.14**
Sowing date	2	476.33***	811.17***	28.75***
Mv*Hv	1	1.96NS	0.27NS	0.15NS
Mv*sd	2	15.33**	1.38NS	0.63*
Hv*sd	2	22.57**	11.31NS	0.25NS
Mv*Hv*sd	2	1.22NS	0.63NS	2.21**
Error	22	1.01	0.81	0.13
Corrected total	35			

Note: *ANOVA= analysis of variance; PHH= plant height; NPPH= number of pods per plant; NSPH= number of seeds per pod; NS= non-significant; *= significant; **= highly significant; ***= very highly significant.*

Appendix Table 8. Analysis of variance (ANOVA) for grain yield, above ground biomass yield, harvest index and hundred kernel weight of intercropped haricot bean as affected by maize varieties, haricot bean varieties and time of sowing

Source of variation	Degrees of freedom	Mean squares			
		Haricot bean characters			
		GYM	ABYM	HI	HKW
Replication	2	20669.90NS	269867.47NS	0.0072*	2.03NS
Maize variety	1	180459.29*	3354.53NS	0.028**	51.36NS
Haricot bean variety	1	96098.97*	219940.68NS	0.0005NS	568.03***
Sowing date	2	5754805.3***	10882802.85***	0.21***	233.86***
Mv*Hv	1	37391.31NS	429809.17NS	0.0007NS	12.25NS
Mv*sd	2	2258.40NS	752566.20**	0.016**	46.36*
Hv*sd	2	2002.15NS	569962.14*	0.014**	37.19NS
Mv*Hv*sd	2	10780.79NS	160246.66NS	0.01**	2.25NS
Error	22	8353.30	102032.55	0.0018	13.36
Corrected total	35				

Note: *ANOVA= analysis of variance; GYH=grain yield; ABYH= above ground biomass yield; HI= harvest index; HKW= hundred kernel weight; NS= non-significant; *= significant; ***= very highly significant*

Appendix Table 9. Analysis of variance (ANOVA) for days to 50 % flowering, days to 90 % maturity, plant height, number of pods per plant and number of seeds per pod of sole and intercropped treatments of haricot bean

Source of variation	Degrees of freedom	Mean squares				
		Haricot bean characters				
		DFH	DMH	PHH	SPPH	NSPPH
Replication	2	0.38NS	0.07NS	5.80NS	7.35NS	0.29NS
Treatments	13	7.22**	17.03**	144.18*	166.66**	5.78**
Error	26	0.74	1.27	3.33	7.00	0.26
Corrected total	41					

Note: *ANOVA= analysis of variance; DFH= days to fifty percent flowering; DMH= days to ninety percent maturity; PHH= plant height; NPPH= number of pods per plant; NSPPH= number of seeds per pod of haricot bean; *= significant; **=highly significant; NS= non-significant*

Appendix Table 10. Analysis of variance (ANOVA) for grain yield, above ground biomass yield, harvest index and hundred kernel weight of sole and intercropped treatments of haricot bean

Source of variation	Degrees of freedom	Mean squares			
		Haricot bean characters			
		GYH	AGYH	HI	HKW
Replication	2	12869.65NS	242567.36NS	0.0009NS	1.02NS
Treatments	13	1305530.51**	2611229.86**	0.048**	131.99**
Error	26	23827.89	90489.59	0.003	14.84
Corrected total	41				

Note: *ANOVA= analysis of variance; GYH=grain yield; ABYH= above ground biomass yield; HI= harvest index; HKW= hundred kernel weight; **= very highly significant; NS= non-significant*

BIOGRAPHICAL SKETCH

The author was born on December 22, 1993 in Bahir Dar Zuria district Dehna Mariam *Kebele* administration. He completed his elementary education in June 2005 at Dehna Mariam elementary school in Bahir Dar Zuria district. The author attended his secondary and preparatory schools from Merawi Secondary School and Merawi Preparatory School, respectively from September 2006 to July 2010 in Mecha district. Then he joined Jmma University in September 2011 and graduated with B.Sc. Degree in Plant sciences in July 2013. He employed and still serving in Amhara Rational regional state technical vocational and enterprise development bureau since 2016 as an instructor in Adet ATVET College. In September 2019 he joined Bahir Dar University to pursue his post graduate study in "Agronomy".