EFFECT OF SPATIAL ARRANGEMENTS OF FABA BEAN VARIETIES INTERCROPPED WITH BREAD WHEAT ON PRODUCTIVITY OF COMPONENT CROPS AT KULUMSA, SOUTHEASTERN ETHIOPIA

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EFFECT OF SPATIAL ARRANGEMENTS OF FABA BEAN VARIETIES INTERCROPPED WITH BREAD WHEAT ON PRODUCTIVITY OF COMPONENT CROPS AT KULUMSA, SOUTHEASTERN ETHIOPIA

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As thesis research advisors, I hereby certify that I have read and evaluated this thesis prepared by Debela Bekele, entitled: **Effect of Spatial Arrangements of Faba Bean Varieties Intercropped With Bread Wheat on Productivity of Component Crops at Kulumsa, Southeastern Ethiopia** under my guidance**.** We recommend that it be submitted as fulfilling the Thesis requirement.

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As members of the Board of Examiners of the MSc Thesis Open Defense Examination, I certify that I have read and evaluated the Thesis prepared by **Debela Bekele** and examined the candidate. We recommend that the Thesis be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Agriculture (Agronomy).

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DEDICATION

This thesis work is dedicated to my late mother Gudo Jima who has passed away in 2019 and to my father Bekele Lenjiso for their persistent help throughout my life career.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that included in the Thesis has been given due recognition through citation.

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BIOGRAPHICAL SKETCH

The author was born on 5th of January 1990, at Dungugi Lafto village, Lume district of East Shewa Zone Oromiya National Regional State, from his mother Gudo Jima and his father Bekele Lenjiso. He attended his elementary school at Koka elementary school (1999-2005) and high school and preparatory (2006-2009) in Mojo high school and preparatory. After passing the Ethiopian School Leaving Certificate Examination (ESLCE) in 2010 he joined Ambo University in 2010 and graduated in Bachelor of Science Degree in Plant Science on June 27, 2012.Aftter his graduation he was employed by Oromiya TVET commission as junior instructor and assigned at Jima Rare TEVET College.

In 2014 he then employed at Ethiopian Institute of Agricultural Research and assigned at Jima Agricultural Research Center in Land and Water Research Process where he worked as Agronomy junior researcher. In 2016 he was transferred to Kulumsa Agricultural Research Center and worked as assistant researcher II until he joined the postgraduate programs of Haramaya University in October 2018 to pursue his Master of Science in Agriculture (Agronomy).

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LIST OF ACRONYMS AND ABBREVIATIONS

C.F	Conversion Factor
CSA	Central Statistical Agency
GFARE	Grain and Feed Annual Report of Ethiopia
GMV	Gross Monetary Value
KARC	Kulumsa Agricultural Research Center
LSD	Least Significant Difference
MOA	Minister of Agriculture, Ethiopia
Mt	Million ton
NPS	Nitrogen, Phosphorus and Sulfur
CORDIS	European Community, Community Research and Development Information Service
PLERFB	Partial Land Equivalent Ratio
GFARE	Global Agricultural Information Network
RCBD	Randomized Complete Block Design
TLER	Total Land Equivalent Ratio
TVC	Total Variable Cost
USDARCS	United States Department of Agriculture Natural Resources Conservation Service

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ABSTRACT

*A field experiment was conducted in 2019 main cropping season at Kulumsa Agricultural Research Center research station, Southeastern Ethiopia with the objectives of assessing the compatibility of faba bean and wheat intercropping, to select suitable varieties of faba bean under different spatial pattern in intercropping and to assess the economic profitability of intercropping faba bean with bread wheat(variety Hulluka) in the area. The treatments were three faba bean varieties (Ashebeka, Hachalu and Tumsa) intercropped with bread wheat in three different planting ratios (1W:1FB, one row of wheat and one row of faba bean; 1W:2FB, one row of wheat and two rows of faba bean; 2W:1FB, two rows of wheat and one row of faba bean) and sole planting of the three faba bean varieties and wheat. The treatments were laid out in randomized complete block design with three replications. The physico-chemical properties of the soil before planting was sandy clay loam with bulk density of 1.36 gm/cm3, pH value of 5.5, 3.9% organic matter, 0.13% total nitrogen and 10.9mg/kg soil available phosphorus. Though non-significant, there was a slight modification on some of the physico-chemical properties of the soil after harvesting for main and interaction effects of varieties and planting ratios. Highest days to 50% flowering (50.2 days) and days to 90% maturity (147.6 days) was recorded from variety Tumsa. The highest number of pods per plant (17.7) was obtained from Variety Hachalu. Variety Ashebeka gave highest thousand kernel weight (858.7g). Planting ratio of 1W:2FB, sole cropped faba bean and planting ratio of 1W:1FB with variety Hachalu gave highest grain yield (3426 3kg ha^{-1}), above ground biomass (11257.3 3kg ha^{-1}) and harvest index of faba bean (36%) respectively. The highest (38.7g) and lowest (35.5g) thousand kernel weight of wheat was recorded in 1W:2FB and 2W:1FB planting ratios respectively. Planting ratio of 2W:1FB gave the highest wheat yield (1896.6kg ha^{-1}), whereas the lowest yield (711.3kg ha^{-1}) was recorded in 1W:2FB planting ratio. The highest (8057.13kg ha^{-1}) and lowest (*3154.9*kgha^{-1}*) above ground biomass yield of wheat was recorded at 2W:1FB and 1W:2FB plating ratios respectively. Planting ratio with a highest sharing of wheat (2W:1FB) gave a highly significant grain yield regardless of the type of faba bean variety. Highest harvest index (32.7%) of wheat was also obtained from 1W:1FB. Higher gross monetary value of 100,591ETB/ha was obtained with planting ratio of 1W:2FB with variety Tumsa. Variety Hachalu when planted at 1W:2FB yielded 98,417 ETB/ha. GMV of 96,854 ETB/ha was gained when Ahebeka was planted at 1W:2FB planting ratio. Sole wheat gave the lowest gross monetary value of 59,752 ETB/ha. This could be due to high price and better competition ability of faba bean with good rain fall distribution in the growing season. From this study, 1W:2FB planting ratio could be used by farmers to get highest benefit.*

Keywords: grain yield, gross monetary value, land equivalent ratio, planting ratios, system productivity,

1. INTRODUCTION

Faba bean (*Vicia faba* L.) is an important legume crop that contains a high protein compared to other legumes amounting to 33 % (El-Sheikh and Ahmed, 2000). It is also a crop of considerable importance as a low-cost food rich in proteins and carbohydrates (Sepetoglu, 2002). In addition to its great nutrition content, faba bean plays essential role in crop rotation. It has the ability to fix nitrogen, and provide a significant level of nitrogen from the soil air using a symbiotic relationship with Rhizobium bacteria (Yucel, 2013)**.**

Faba bean production occupied nearly 2.1 x 10^6 ha worldwide (FAO, 2017). Its global production is 4.4 million tons (FAOSTAT, 2019). The main faba bean global producers are China (1.64 Mt), Ethiopia (0.92 Mt), Australia (0.34 Mt), France (0.27 Mt) and Sudan (0.16 Mt) (FAOSTAT, 2019).

Faba bean is an important pulse crop in terms of area coverage and volume of annual production in Ethiopia (Tamene and Tadese, 2013).The crop takes the largest share of the area under pulses production (CSA, 2019). The annual area coverage of the crop in Ethiopia is 492,271.60 hectares with the total production and productivity of 1.04 million tons and 2.1 tons/ ha respectively (CSA, 2019). It is a major staple food crop among pulses and it is mainly grown in the mid and high altitude areas of the country with an elevation ranging from 1800-3000 meters above sea level (Musa and Gemechu, 2006). Some limiting factors of faba bean production are climatic conditions, edaphic factors, disease problem and agronomic practices (National Planning Commission, 2016). One way by which problems associated with soil fertility (Ehrmann, 2014), disease problem (Azam-Ali, 2003) etc. could be solved is through crop diversification such as multiple cropping.

It is mostly grown as a sole crop but in some countries intercropping with cereals is a common practice (Tosti and Guiducci, 2010; Dordas and Lithourgidis, 2011; Dhima *et al*., 2013). Most faba bean production in the industrialized countries is sole cropped, but in other parts of the world (Asia and Africa) intercropping of faba bean with other cereals is a common practice (Zhang *et al*., 2004).

Wheat (*Triticum spp.*) is one of the most important cereal crops in terms of area and production in the world. Global wheat production in 2017 was 744.5 million tons (FAO, 2017). Ethiopia is the second largest wheat producer in Sub-Saharan Africa next to South Africa**.** It is one of the major staple crops in the country in terms of both production and consumption. In terms of caloric intake, it is the second most important food (14%) in the country next to maize (FAO, 2019b). It is mainly grown in the highlands of Ethiopia, which lie between 6 and 16° N, and 35 and 42° E, at altitudes ranging from 1500 to 2800 meters above sea level (MoA, 2012). There are two species of wheat grown in Ethiopia: durum wheat, accounting for 60 percent of production, and bread wheat, accounting for the remaining 40 percent (Bergh *et al*., 2012).

The introduction of semi-dwarf wheat varieties and increased fertilizer use for the last four decades is a dominant feature of the highland crop agriculture. As a result single cropping of high-yielding and high fertilizer-input varieties has been promoted for several decades as an approach to enhance food production in the country. However, the increase in input costs, reduction in farm size and soil quality, and increasing problem with buildup of insect pests, diseases and weeds have threatened the ecological and economic sustainability of wheat production in these highlands (Georgis *et al*., 1990). Despite this, a resource use study in northern Ethiopia has shown that farmers have changed their cropping system from growing a pure crop of improved varieties of semi-dwarf wheat to mixed intercropping with a small proportion of faba bean and field pea (Getachew *et al*.,2008). (Getachew *et al*.,2008) further described that the reasons for such a practice was land shortage coupled with the need to produce the cereal as main crop and the legumes as component crops to generate additional benefits, enabling them a spatial crop intensification system under the prevailing arable land scarcity.

Multiple cropping is the intensification of cropping in time and space dimensions. It is growing of two or more crops on the same field in a crop season (Degla *et al.,* 2016). Multiple cropping systems use management practices where the total crop production from a piece of land is achieved by growing single crops in close sequence, growing several crops simultaneously, or combining single and mixed crops in some sequence e.g. double cropping and intercropping (USDARCS., 2011). The agronomic and economic advantage of multiple cropping varies depending on agro ecological, farming system and other associated agricultural related factors (USDARCS., 2011).

Intercropping is the agricultural practice of cultivating two or more crops in the same land at the same time (Xu *et al*., 2008). It is an intensive management for crop production which aims to match efficiently crop demands to the available growth resources and labor. It is relatively common in tropical and temperate areas because of the effective utilization of water (Xu *et al*., 2008), nutrients (Xia *et al*., 2013; Zhang and Li, 2003) and solar energy (Yang *et al*., 2014).

The most common advantage of intercropping is the production of greater yields on a given piece of land by making more efficient use of the available growth resources. This could be due to different rooting characteristics, canopy structure, height, and nutrient requirements or resource use at different times (Eskandari and Kazemi 2011).

Sullivan (2003) reported that staggered maturity dates as well as development periods in intercrops take advantage of variations in peak resource demands for nutrients, water and light. Intercropping legumes with cereals contributes some nitrogen to the cereal component through residual nitrogen (Adu-Gyamfi *et al*., 2007). A three years study of sorghum/groundnut and sorghum/soybean intercropping in Asosa (Ethiopia) showed that sorghum/groundnut intercrop had the highest sorghum yield at all growing season (Dereje *et al.* 2016). The gross income and land equivalent ratio indicate greater economic benefit with intercropping of groundnut in 1:1 proportion and simultaneous planting than sole planting (Dereje *et al.* 2016).

The majority of intercropping systems involve legume/cereal combinations, inter-specific facilitation occurs when one plant species enhances the growth of another plant species and has been observed mainly in legume/cereal systems (Li *et al*., 1999, 2001), and most of the research that has been conducted on intercropping has therefore focused on the legume/cereal intercropping, a productive and sustainable system (Ghosh *et al.*, 2009; Lithourgidis *et al.*, 2011; Tosti *et al.*, 2010).

Spatial arrangement of faba bean with barley around Debre Birhan area revealed that significantly greater land equivalent ratio (LER) was obtained in intercropping than both crops when planted as sole. The 2B:1FB (one row of faba bean intercropped in two rows of barley) was more productive than other planting patterns (1B:1FB and 1B:2FB). All spatial arrangements had the LER values of more than one (LER> 1) (Girma *et al*., 2019). It indicated that intercropping had economic advantages in land use efficiency (Girma *et al*., 2019).

Faba bean and bread wheat are adapted to highland agro ecological niches whereby mono cropping is a dominant crop production system (CSA, 2004). This system is associated with occurrence of crop diseases, soil acidity and fertility problems, high population and small land holdings that are ended in low crop production and productivity.

Arsi zone is potential area for both faba bean (FAO, 2010) and wheat. The production of wheat is highly dependent on inorganic fertilizer for plant nutrient, and agricultural pesticides for disease and weed control. The increasing price of these inputs increased cost of production which leads to minimum net income. This forced farmers to use crop rotation in the area. Some farmers practice crop rotation by rotating cereals (wheat and barley) with legumes (faba bean and field pea) (Musa, 2014). They do this to minimize the amount of fertilizer required and break pest cycle (disease, weed and insect) for cereal especially wheat. However most farmers do not use this rotation as required because of land shortage. They do not want to loss wheat every year. Because of this, alternative cropping system is needed to solve this problem. However, there is lack of information concerning inter-cropping of wheat with faba bean in the area. The yield advantage in implementing intercropping could be tested and validated by knowing the complementarity of the component crops in the given area with respect to space and time dimension. Therefore, the objective of this study was to assess the compatibility of faba bean /wheat inter cropping, to select suitable variety of faba bean under different spatial patterns of intercropping, and to assess the economic feasibility of intercropping faba bean with bread wheat in the area.

2. LITERATURE REVIEW

2.1. Production of the Component Crops

2.1.1. Faba bean and Productivity

Nowadays faba bean is widely grown in temperate and subtropical regions and at higher altitudes in tropics. In tropical Africa it is mainly found in east Africa, especially in Sudan and Ethiopia (Mussa and Gemechu, 2006). Faba bean requires a cool season for best development and the growing seasons should have little or no excessive heat, optimum temperatures for production range from 18 to 27 C^{o} (Link *et al.*, 2010). Faba beans grow best on good-structured clay or loam soils with pH 6.5-9, tolerates nearly any soil type (Jensen *et al*., 2010). Plants are reasonably tolerant to water-logging, but are more prone to infection from foliar diseases such as chocolate spot (*Botrytis fabae* Sard.) and rust (*Uromyces fabae* Pers.) under waterlogged conditions. Any factor tending to weaken the crop, such as acid soil, phosphate deficiency and water logging of the soil, renders the plant more liable to aggressive infections (Wilson, 2008).

Faba bean production is more evenly distributed around the world than most other grain legumes (FAOSTAT, 2019). Faba bean is produced in more than 66 countries over the world (Torres *et al*., 2006). It founds on 5th rank under pulse crops world average production. The annual production of this crop is about 4.5 million tons in average (Merga *et al.,* 2019). The cultivated faba bean world area was estimated to be 2433 thousand hectares in 2012–14 (FAOSTAT, 2019). China contributes 37.26% of the total global area of production followed by Ethiopia, Australia and France with 21.03, 7.82 and 6.05%, respectively (FAOSTAT, 2019). According to FAOSTAT (2019), average grain yield of faba bean in the world is 1807 kg /ha.

Africa ranks second in faba bean production in the world which is 30% (FAO, 2019c).From Africa Ethiopia is the first faba bean producer. Ethiopia is believed to be secondary centers of diversity for faba bean (Torres *et al*., 2006). The production is mainly concentrated in the high altitudes of Ethiopia ranging between altitudes 1800-3000 m.a.s.l. with annual rain fall ranges from 700-1100mm and has suitable environmental conditions (Asfaw, 1985).

The Central Statistical Agency (CSA, 2019) reported that faba bean is planted to about 492,271.60 ha, with an annual production of about 1,041,953.5 tones, 3.94 % of the total grain production and yield of 2100 kg/ha in Ethiopia. Despite its importance, the productivity of the crop is far below the potential and is constrained by several limiting factors (Yohannis, 2000). Shiferaw *et al*. (2013) also mentioned the productivity of faba bean is far below the expected potential due to low in put usage, natural disasters like snow storm, depletion of macronutrient from cultivable land and unavailability of essential nutrients.

Cultivated faba bean is mainly used as human food in developing countries and as animal feed for pigs, horses, poultry, and pigeons in industrialized countries (Rubiales, 2010 and Flores *et al*., 2012). Faba bean is most commonly included in the diets of peoples of the Middle East, the Mediterranean region, China and Ethiopia (Jensen *et al*., 2010). The nutritional value of faba bean is high and in some areas is considered to be superior to peas or other grain legumes (Crepon *et al*., 2010). It is a significant source of protein rich food (Jensen *et al.*, 2010). It contains a high protein compared to other legumes amounting to 33 % (El-Sheikh and Ahmed, 2000). It also contains approximately 50% of carbohydrate and no more than 15% of crude lipid (Proskina *et. al*., 2016**)**. It is a good source of lysine rich protein and good source of *levadopa* (*L-dopa*), a precursor of dopamine, can be potentially used as medicine for the treatment of Parkinson's disease (Kumar *et al.*, 2013).

However, the presence of chemical compounds like vicine and convicine in the cotyledons may cause health problems in particular situations (Crepon *et al*., 2010). In animal nutrition tannins, vicine, and convicine are faba bean seed constituents, which have been demonstrated in several studies to have an anti-nutritional effect in the diet of monogastric animals (Crepon *et al.*, 2010).

Broad beans are one of the most popular legumes in Ethiopia. It is a crop of manifold merits in the economy of the farming communities in the highlands of Ethiopia. It serves as a source of food and feed and a valuable and cheap source of protein. Faba bean also plays a significant role in soil fertility restoration in crop rotation through fixation of atmospheric nitrogen (Asfaw *et al*., 1994; Yohannis, 2000). It is tightly coupled with every aspect of Ethiopian life.

It is mainly used as an alternative to peas to prepare flour which is used to make a stew used widely in Ethiopian dishes. Boiled broad bean (*nifro* in Amharic) is also common in Ethiopia.

2.1.2. Wheat

The two common species of wheat are bread wheat (*Triticum aestivum* L.) and durum wheat (*T. turgadum*) and 95% of consumed wheat is bread wheat (Hrist, 2012). Many species of wheat together make up the genus *Triticum* and the most widely grown is common wheat (*T. aestivum*).

Wheat is grown on more land area (220.4 million hectares) than any other food crop worldwide in 2014 (FAOSTAT, 2014). In 2020, world wheat production was estimated to be 763.4 million tones (FAO, 2020) making it the second most-produced cereal after maize (FAOSTAT, 2014).

Many Studies indicate that wheat yield of other African countries such as Egypt, South Africa and Kenya have 67, 35 and 30 quintals per hectare, respectively (Adugnaw & Dagninet, 2020).In sub-Saharan African countries, wheat is also a strategic commodity which generates farm income and improves food security status (Amentae *et al.,* 2017; Minot *et al.*, 2015). Many African countries are producing wheat for both consumption and sale, but the level of production and sale is varied between countries (CSA, 2012).

Ethiopia is the center of diversity of wheat (GFAR, 2013). Wheat is one of the most important cereals cultivated in Ethiopia. It ranks third after sorghum (Sorghum bicolor) and maize (*Zea mays*) in area coverage, while second in total production after maize (CSA, 2015). Ethiopia is the second largest wheat producer in Sub-Saharan Africa next to South Africa (White *et al.*, 2001). However, the Ethiopian government is forced to import wheat every year because of high demand than supply (WFB, 2012). Wheat production in the country is adversely affected by low soil fertility and suboptimal use of mineral fertilizers in addition to diseases, weeds, erratic rainfall distribution in lower altitude zones, and water-logging in the vertisols areas (Amanuel *et al*., 2002).

Wheat is mainly grown in the highlands of Ethiopia, which lies between 6 and 16° N and 35 and 42° E, at altitude ranging from 1500 to 2800 meters above sea level and with mean minimum temperatures of 6 ^{0}C to 11 ^{0}C (Hailu, 1991;MOA, 2012).

Ethiopia ranks 31st in the world with 4.2 million quintals produced on 1.7 million hectares of land (Goshu *et al*., 2019). Area under wheat in the main season is about 1.747 million hectares, making up 16% of the total cereal crops area (CSA, 2019).Production of wheat in Ethiopia is 4,838,074.1tonnes in 2018/19 main cropping season(CSA, 2019).National wheat productivity in 2018/19 was estimated to be 2.764tonnes/ha (FAO, 2019b). Oromia Regional State accounts for over half of national wheat production (54 percent), followed by Amhara (32 percent); Southern Nations, Nationalities and Peoples (9 percent); and Tigray (7 percent) (CSA, 2013). Central-Eastern Oromia, comprising Arsi, West Arsi, Bale and East Shewa zones, accounts for approximately 42 percent of the overall wheat production of Ethiopia with 1.89 million tonnes in 2016 (FAO, 2019b).

Though bread and durum wheat are types of wheat produced, bread wheat is the major crop varieties grown in Ethiopia although farmers grow both varieties mixed together (GFAR, 2013). Despite the large area coverage under wheat, the national average yield in Ethiopia is about 2.7 t/ ha (CSA, 2019). This is attributed to cultivation of unimproved and low yielding varieties, inadequate and erratic rainfall, poor agronomic practices, diseases and insect pests which are among the principal limitations to wheat production in Ethiopia (Gorfu and Hiskias, 2000). Wheat is one of the major staple crops in the country in terms of both production and consumption. In terms of caloric intake, it is the second most important food in the country behind maize (FAO, 2014).

Global demand for wheat is increasing due to the unique viscoelastic and adhesive properties of gluten proteins, which facilitate the production of processed foods, whose consumption is increasing as a result of the worldwide industrialization process and the westernization of the diet (Shewry *et al.*, 2015).

It is a major diet component because of the wheat plant's agronomic adaptability with the ability to grow from near arctic regions to equator, from sea level to plains of Tibet, approximately 4,000 m (13,000 ft) above sea level. In addition to agronomic adaptability, wheat offers ease of grain storage and ease of converting grain into flour for making edible, palatable, interesting and satisfying foods.

Wheat is the most important food plant for one third of world's population (Hrist, 2012). It supplies about 20% food calories for world people (Gibson and Benson, 2002). Wheat has great nutritional value and contains starch (60-90%), protein (11-16.5%), fat (1.5-2%), inorganic ions(1.2-2%) and vitamins (Ali *et al.,* 2014). Globally, it is the leading source of vegetal protein in human food, having a protein content of about 13 % (Day *et al*., 2017). The by-products of wheat are useful for livestock and poultry feed and the straw may be used for newsprint, paper board and other products (Gibson and Benson, 2002).

In Ethiopia, wheat grain is used for preparation of food and local beverages like the traditional staple pancake ("*injera*"), bread ("*dabo*"), local beer ("*tella*"), and several others local food items (i.e., "*dabokolo*","*ganfo*", "*kinche*") and its straw is used for animal feed and roof thatching.

2.2. Inter-cropping and its Advantages

Intercropping is growing of two or more crops in the same field, where the component crops are not necessarily sown at the same time nor harvested at the same time, but they are grown simultaneously for a portion of their growing periods (Lithourgidis *et al.*, 2011). Intercropping can include: annual plants with annual plants intercrop; annual plants with perennial plants intercrop; and perennial plants with perennial plants intercrop (Eskandari *et al*., 2009; Ghanbari and Lee, 2003).

Intercropping is divided into the following four groups (Ofori and Stern, 1987): Row-intercropping: growing two or more crops simultaneously where one or more crops are planted in regular rows, and crop or other crops may be grown simultaneously in row or randomly with the first crop. Mixed- intercropping: growing two or more crops simultaneously with no distinct row arrangement. This type of intercropping can be suitable for grass-legume intercropping in pastures. Strip-intercropping: growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically. Relay- intercropping: growing two or more crops simultaneously during part of the life cycle of each crop. A second crop is planted after the first crop has reached its reproductive stage but before it is ready for harvest. Within relay- intercropping system, there is normally one main crop and one or more added crops often sown later in the season, with the main crop being of primary importance for economic or food production reasons (Lithourgidis *et al.*, 2011).

Intercropping is one of the most common practices used in sustainable agriculture. It has an important role in increasing the productivity and stability of yield in order to improve resource utilization and environmental factors (Lithourgidis *et al.*, 2011). Within relay-intercropping system, there is normally one main crop and one or more added crops often sown later in the season, with the main crop being of primary importance for economic or food production reasons (Lithourgidis *et al.*, 2011). Inter-cropping is an attractive strategy for increasing productivity and labour utilization per unit area of available land and to intensify land use (Seran and Brintha, 2010). Inter-cropping production systems provide farmers with opportunities to increase production and returns while providing cover to soils that are typically highly erodible times (Eskandari and Kazemi, 2011).

Inter-cropping cereals and forage legumes is also an important benefit in enhancing forage quality (Dordas and Lithourgidis, 2011). Inter-cropping benefits farmers by providing them a way to grow a wide array of crops, freeing them from the burden of purchasing food and feed. It can be also eco-friendly approach for reducing weed problems through non-chemical methods (Horwith, 1985). In the tropics, cereal/legume intercropping is a common practice aimed at minimizing risks associated with monoculture. In areas where environmental stresses are common, inter cropping is insurance against total crop failure. Inter-cropping also reduces damage from insects and diseases (Drinwater *et al*., 2002). Intercropping may provide a balanced diet, reduce labor peaks, minimize crop failure due to adverse effects of biotic and abiotic factors, protect soil against erosion, improve the use of limited resources, increase stability of yield and provide higher returns (Akter *et al.*, 2004; Chu *et al*., 2004; Tsubo *et al*., 2005).

2.2.1. Pest Management

One important advantage of intercropping is its ability to reduce pest and disease damage (Sullivan, 2003). It has been recognized as a farming system that will reduce plant disease incidence. It was found that better disease control is possible either when host plants are interspersed with non-host plants, or when one crop modifies the environment of the second crop in such a way that the latter is less susceptible to disease attack (Sullivan, 2003). Keswai and Mreta, (1980), reported that intercropping green gram with soybean or millet resulted in a significant reduction in powdery mildew as compared to the disease incidence when green gram was planted as a sole crop. Intercropping legumes with cereals is known to improve disease control (Boudreau and Mundt, 1992; Fernández-Aparicio *et al*., 2007, 2010; Schoeny *et al*., 2010). Chocolate spot reduction has been reported in faba bean intercropped with cereals, but there are conflicting reports on the effect in intercrops with other legumes (Sahile *et al*., 2008).

In general, strategies involved in reducing pest infestation and damage in intercropping can be divided into three groups: first: delimiter crop hypothesis: this way that second species, breaks down the ability of a pest in attack to its host, and is used more in proprietary pests. Second: trap crop hypothesis: means that second species, attracted towards their pest or pathogen that normally does damage to the main species, and is used more in general insect pests and pathogenic agents. Third: natural enemies hypothesis: this way that predators and parasites are more attracted in intercropping, than the mono-cropping, and thereby diminishes parasitized and pray (Danso *et al*., 1987).

In a review by Francis, (1989) on intercropping, in 53% of the experiments intercropping reduced the insect pest, and in 18% increased the insect pest than the pure cropping. Intercropping systems increases biodiversity like the natural ecosystems. This increase in diversity reduces insect pest damage and diseases (Anil *et al*., 1998).

It is well known that weeds interfere with crops causing serious impacts through either competition (for light, water, nutrients and space) or allelopathy. Intercropping patterns are more effective than mono-cropping in suppression of weeds, but their effectiveness varies greatly (Girjesh and Patil, 1991). Intercrops may demonstrate weed control advantages over pure cropping in two ways. First, greater crop yield and less weed growth may be achieved if intercrops are more effective than pure cropping in usurping resources from weeds or suppressing weed growth through allelopathy. Alternatively, intercrops may provide yield advantages without suppressing weed growth below levels observed in component pure cropping if intercrops use resources that are not exploitable by weeds or convert resources to harvestable material more efficiently than pure cropping (Matt and Dyck, 1993). Because of the difficulty of monitoring the use of multiple resources by intercrop/weed mixtures throughout the growing season, identification of specific mechanisms of weed suppression and yield enhancement in intercrop systems has so far proven elusive (Matt and Dyck, 1993). In mono-cropping systems rarely, all available natural resource such as moisture, nutrients and light are used by plant, consequently released niche are captured by the weeds. If used plants in the intercropping, in the use of resources are complementary, in this case intercropping system with more and effective use of ecological resources, and filling the empty niche, leads to weed control are better and effective than the mono-cropping system (Saudy and El-Metwally, 2009). The Sorghum/ground nut intercrop was found to be effective in controlling striga weeds (Dereje *et al.*, 2016).

2.2.2. Biological Nitrogen Fixation

Biological nitrogen fixation (BNF) is a natural process in legume crops, where atmospheric nitrogen (N_2) is fixed into ammonia (NH_3) in plant root nodules by a symbiotic form of Rhizobia *(Rhizobium leguminosarum* bv. viciae) a gram-negative *Proteobacteria.* The plant assimilates this NH_3 into proteins, nucleic acids and other nitrogenous compounds (Strodtman and Emerich, 2009).

According to Herridge *et al*. (2008), BNF from legume crops contributes 2.95 teragram N to agriculture globally. Biological nitrogen fixation has a high potential for low input systems, as in large regions of Africa, where more N is removed from the soil than is replenished, which results in depletion of soil nutrients and land degradation (Cocking, 2009).

Atmospheric nitrogen (N) fixation in crop and pasture legumes also plays a key role in providing human and livestock protein and for maintaining soil fertility in agro-ecosystems (Unkovich *et al.*, 2010). Improving N fertilizer efficiency and exploitation of biologically fixed N, biological nitrogen fixation are thus of great importance for long-term sustainability of crop production in agro-ecosystems (Unkovich *et al.*, 2008). The global high price for N fertilizer and the overall environmental impact of excessive fertilizer use (Chianu *et al*., 2011; Fan *et al*., 2006) warrant a growing interest in legume BNF, especially for smallholder farmers in the tropics.

Conservation of soil fertility in intercropping is a form of rotation that each season is done on land (Eskandari *et al*., 2009; Anil *et al*., 1998; Fujita *et al.,* 1992).In practice of the legume-based intercropping systems the non-legume components derive N from the legume components (Banik *et al*., 2006). However, the extent to which this is true is still a subject of intense debate (Ofori and Stern, 1987; Francis, 1989; Willey, 1990). Others concluded that there is no direct transfer of N from legume to the non-legume crop in intercrop systems, but the N fixed by the legume is made available for subsequent crop (Stern, 1993; Yunusa and Rashid, 2007; Urbatzkaa *et al.,* 2009). But it is true that inter/cropping legume with non-legume crops can reduce soil depletion (Russelle and Hargrove, 1989). Rhizobium bacteria are able to have a symbiotic relationship with plants of leguminosae family, and thereby fix atmospheric nitrogen into available nitrogen for plants uptake. And the result nitrogen (as an essential element for soil fertility and plant growth) is added to the soil (Fujita *et al.,* 1992). There are several reports indicating that increasing the nitrogen content in non-legume plants, due to the intercrops of these plants with plants of leguminosae family (Eskandari *et al*., 2009; Anil *et al*., 1998).

Faba bean is seen as an agronomically viable alternative crop to cereal, with a potential of fixing free nitrogen up to 300 kg N/ha (Kumar *et al.,* 2013). It is one of the best crop species for atmospheric N fixation, with global annual biological nitrogen fixation inputs estimate at around 0.3 Teragram year1y (Herridge *et al*., 2008). In contrast to other legumes, faba bean can maintain high rates of biological nitrogen in the presence of high amounts of available N in the soil (Hardarson *et al*., 1991; Schwenke *et al.,* 1998; Turpin *et al*., 2002), which is attributed to its low rooting density and rooting depth compared with other legumes. Up to 96% of the N taken up by the crop has been measured as nitrogen derived from atmosphere (Lopez-Bellido *et al.,* 2006).

Biological nitrogen fixation by faba bean under field conditions range from 15 to 648 kg N /ha (Schwenke *et al.*, 1998; Kopke and Nemecek, 2010). The high variation may be the result of variation in specific growing conditions, genotypic variations, and variations in the methods used for quantifying biological nitrogen fixation. There is sufficient capacity for BNF to supply the majority of the faba bean N requirements for growth and field data indicate that N fixation can support the accumulation of 10-15 t shoot dry matter (DM) /ha (Rochester *et al*., 1998). However, the formation of a functional symbiosis between legume and rhizobia is dependent upon many environmental factors and management practices (Kopke and Nemecek, 2010).

2.2.3. Increase Productivity

The use of intercropping became one of the strategies used by producers in order to reach high productivity. It produced more than a pure cropping of same land amount (Caballero and Goicoechea, 1995). The reason for increasing of productivity is that it increases the efficiency of using environmental resources (Okigbo, 1990). This is due to the interaction between components in intercrops and the difference in competition for the use of environmental resources (Mahapatra, 2011).

The economic return or monetary gain per unit area and time is one of the major considerations for adoptions of a certain cropping system and yield is the foremost agronomic parameter to compare the importance of component crop in any type of cropping system (Eskandari *et al*., 2009). So many researches indicated the increment of total yield and economic return in inter-cropping system than sole cropping system (Girma *et al.*, 2019; Kico *et al*., 2016 and Getachew *et al*., 2008).

Yield advantages have been recorded in many legume/cereal inter-cropping systems, included soybean/sorghum (Ghosh *et al*., 2009), cowpea/maize (Abou-keriasha *et al*., 2011), faba bean/wheat (Abou-Keriasha *et al*., 2008) and vetch/oat (Tuna and Orak, 2007). Liben *et al.* (2002) and Eskandari and Ghanbari (2010) showed that grain yield, harvest index and thousands grain weight of wheat or maize were reduced in intercropping, while in bean decreased only in grain yield. Odhiambo and Ariga, (2001) with maize and beans intercrops in different ratios found that increased production due to reduced competition between species compared with competition within species. Ghanbari and Lee, (2002) reported that dry matter production in wheat and beans intercrops had been more than their pure cropping. Also, Martin and Snaydon, (1982) in their study reported that grain and dry matter yield in bean and barley intercrops was more than their sole cropping. Willey (1990) considered intercropping as an economic method for higher production with lower levels of external inputs. This increasing use efficiency is important, especially for small-scale farmers and also in areas where growing season is short (Altieri, 1995). Getachew *et al*. (2008) also noticed that intercropping of wheat with faba bean increased both total yield and land-use efficiency by 3%-22%.

In the same manner and elsewhere, the beneficial effects of intercropping of wheat with legumes was ascribed to the more efficient use of environmental resources by the intercrops than by pure stands (Banik, 1996; Bulson *et al*., 1997; Haymes and Lee, 1999). Measurements such as the total yield, total revenue, land equivalent ratio, crowding coefficient, aggressivity value and system productivity index have been used to quantify the efficiency of intercropping systems relative to sole cropping (Hiebsch and McCollum, 1987; Getachew *et al.,* 2006). However, the LER is the most used convention for intercrop vs. sole crop comparisons.

In Ethiopia, food production for a rapidly growing population from a continually shrinking farm size is a prime developmental challenge. Researches indicated that inter-cropping is a good way of using land efficiently. Mixed intercropping of wheat with faba bean was compared with sole culture of each species in 2002 and 2003 at Holetta Agricultural Research Center, in the central highlands of Ethiopia and intercropping increased the land equivalent ratio by +3% to +22% over sole cropping (Getachew *et al*., 2008). Increasing the faba bean seed rate in the mixture from 12.5 to 62.5% reduced wheat grain yield from 3601 kg /ha to 3039 kg ha^{-1} but increased faba bean grain yield from 141 kg $ha^{-1}$to 667 kg ha^{-1}. Nonetheless, the highest total grain yield of 4031 kg ha^{-1}, gross monetary value of US$ 823, system productivity index of 4629 and crowding coefficient of 4.70 were obtained when wheat at its full seed rate was intercropped with faba bean at a rate of 37.5% (Getachew *et al*., 2008).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

Field experiment was conducted in 2019 main cropping season at Kulumsa Agricultural Research Center (KARC) main compound. It is located in Gora selengo kebele, Tiyo district of Arsi Zone, Oromia Regional State, Southeastern Ethiopia (Figure 1). The experimental site is located at 8°01'N latitude and 39°09'E longitude, 167 km southeast of Addis Ababa at altitude of 2200 meters above sea level. It receives average annual rainfall of 809.2 mm and has a uni-modal pattern rain fall. The peak season of the rain fall is from July to August. The average annual minimum and maximum temperatures are 9.9 and 23.1 °C, respectively (Abayneh, 2003). The soil type is luvisol/eutric nitosols with a good drainage system. It contains 5.5% organic matter, 0.25% nitrogen and its pH is 5.5-6.0 (KARC, 2000).

3.2. Experimental Materials

Three faba bean varieties Tumsa, Ashebeka and Hachalu and bread wheat variety Hulluka were used for the experiment (Table 1). Urea and blended NPS fertilizers was used as a source of nitrogen and phosphorus, respectively.

3.3. Treatments and Experimental Design

The treatments consisted of three faba bean varieties inter-cropped with wheat in three different ratios and sole Ashebeka, sole Hachalu, sole Tumsa and sole Hulluka. Randomized complete block design (RCBD) with three replications was used for the experiment.

Table 1. Treatment combinations

Faba bean varieties	Planting ratios		
	1W:1FB	1W:2FB	2w:1FB
Ashebeka	AshebekaX1W:1FB	AshebekaX1W:2FB	AshebekaX2w:1FB
Hachalu	HachaluX1W:1FB	HachaluX1W:1FB	HachaluX1W:1FB
Tumsa	TumsaX1W:1FB	TumsaX1W:1FB	TumsaX1W:1FB

3.4. Experimental Procedures

The field was ploughed by disc plough and harrowed using tractor before planting. Then it was levelled manually using hand tools. Both faba bean and wheat were planted simultaneously on 17 July, 2019. Recommended seed rate of wheat (150kgha^{-1}) and faba bean (200kgha^{-1}) was used.Seed source for both faba bean and wheat was Kulumsa Agricultural Research Center. The crops were planted in row in which the inter row spacing for faba bean and wheat was 40cm and 20cm respectively where wheat was planted between faba bean rows. In 1:1 ratio wheat was planted between every two faba bean rows, so it was 20cm apart from faba bean from both sides. In 1:2 ratio wheat was planted between alternate faba bean rows and there was 40cm between faba bean rows and 20cm between faba bean and wheat rows. In 2:1 ratio faba bean was planted after two wheat rows and there was 20cm between wheat rows and 20cm between faba bean and wheat rows. The three faba bean varieties and wheat was also planted as sole. Manual row marker was used for planting. Blended NPS fertilizer at recommended rate of 120kgha^{-1} for faba bean was applied to all treatments except sole wheat which received both blended NPS at the rate of 180kgha^{-1} and urea at the rate of 100kgha^{-1} according to recommendation for wheat.

The experimental plot size was 2.5mx4m (10m^2) for all inter-cropped treatments and 2.4mx4.17m (10m^2) for both sole cropped crops. Plots received different treatments had different number of rows with equal row length (4m), except sole cropping which was 4.17m. In 1:1 treatment (wheat/faba bean) contained six wheat rows and six faba bean rows. The 1:2 treatment (wheat/faba bean) contained three wheat rows and six faba bean rows. The 2:1

treatment (wheat/faba bean) contained eight and four wheat and faba bean rows respectively. Sole wheat and faba bean cropping contained 12 and six rows, respectively. Therefore, the gross plot size for all treatments was $10m^2$ with net plot area of $3.8m^2$ for all treatments. This was 1.9mx2m, 1.7mx2.24m, 1.9mx2m, 1.8mx2.11, and 1.6mx2.38m for treatment 1:1, 1:2, 2:2, sole wheat and sole faba bean, respectively. Numbers of rows harvested as net plot was depend on the treatments. Four rows were harvested for both crops in 1W:1FB treatment. For treatment 1W:2FB, two rows of wheat and four rows of faba bean were harvested and for treatment 2W:1FB, six rows of wheat and three rows of faba bean were harvested. Eight and four rows of wheat and faba bean were harvested from sole wheat and sole faba bean, respectively.

Table 2.Description of faba bean and wheat varieties used in the experiment

Varieties name	Year of release	Area of adaptation		Maturity days	On station productivity (q/ha)
		Altitude (m a.s.l.)	Rain fall (mm)		
Hachalu	2010	Mid-to-high altitude (waterlogged areas)	600-900	121-156	32-45
Tumsa	2010	1900-2300	600-900	121-176	25-69
Ashebeka	2015	Mid-to-high altitude (waterlogged areas)	500-800	120-154	25-48
Huluka (wheat)	2012	2200-2600	500-800	133	44-70

Source: Kulumsa Agricultural Research Centre

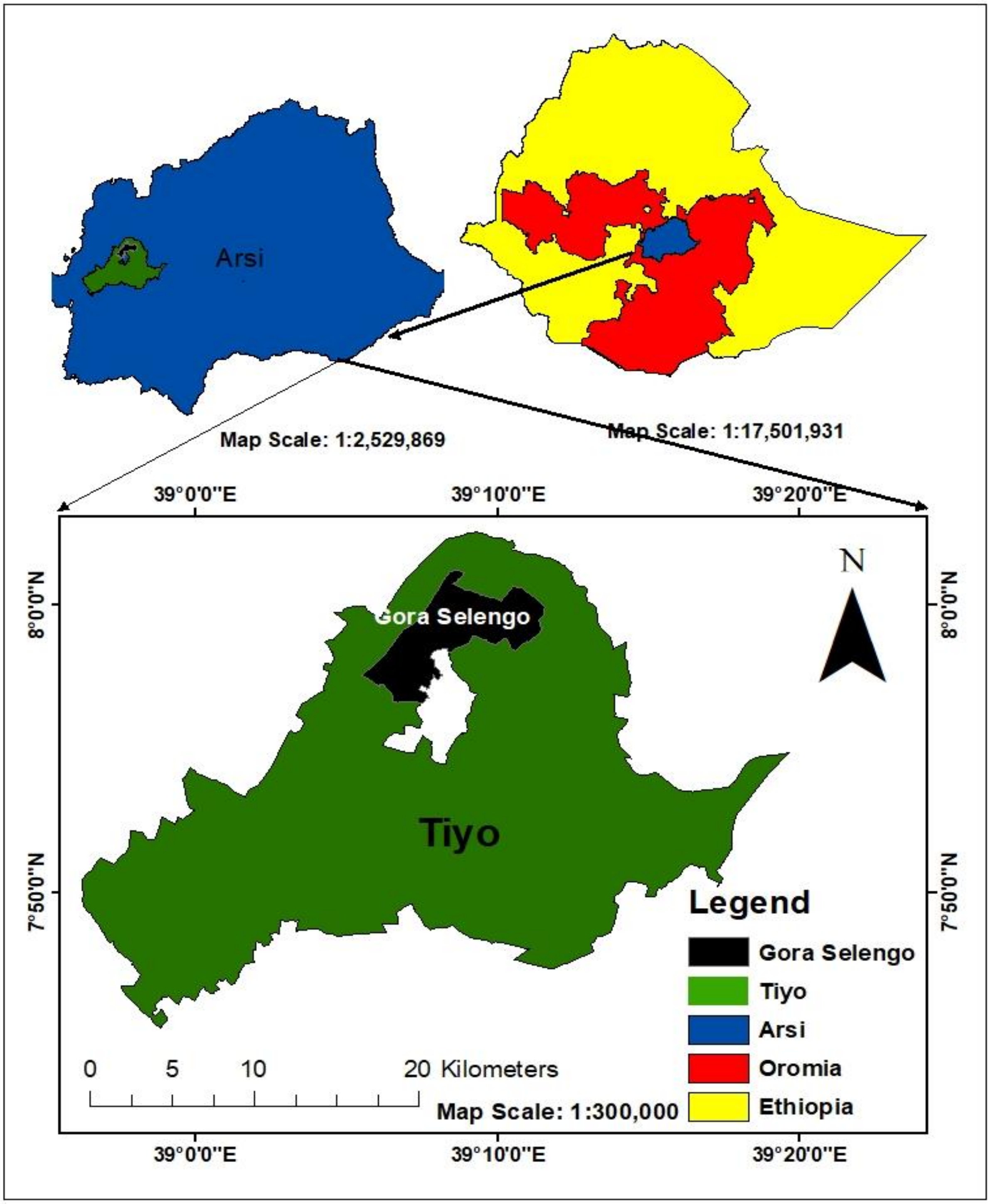

Figure 1. Location map of the study area

3.5. Soil Sampling and Analysis

Before plating soil samples were collected from 0-30 cm depth per replication to obtain representative composite soil samples. After harvesting soil samples were taken on plot bases. The samples were air-dried, ground and sieved through a 2mm sieve and made ready for analysis (FAO, 2008).

Soil samples collected before planting were analyzed for texture, pH, organic matter, total nitrogen and available phosphorus. After harvest bulk density, available P, pH, organic matter, and total nitrogen were analyzed. Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The pH of the soil was measured in the supernatant suspension of a 1: 2.5 soil to water ratio using a pH meter by potentiometer method (Rhoades, 1982). Organic matter was determined by wet oxidation method as described by Walkely and Black (1934). Available P was determined by bray *et al*. (1954) method. Total nitrogen was determined using Kjedahl method as described by Bremner and Mulvaney (1982).

3.6. Plant Tissue Sampling and Analysis for Nitrogen Content

At maturity, five non-boarder wheat plants samples were randomly collected from each plot and partitioned into grain and straw. The straw samples were washed with distilled water to clean the samples from contaminants such as dust. The straw samples were oven dried at 70 ^{0}C to constant weight. After drying, the samples were ground and passed through 0.5 mm sieve. Then the samples were analyzed for nitrogen following wet digestion method.

3.7. Data Collected

3.5.1. Phenological and growth parameters for faba bean component

Days to flowering: number of days from planting to flowering of 50% of plants was recorded by careful observation (Tamene, T. 2008).

Days to maturity: number of days from planting to when plants attained 90% physiological maturity was recorded.

Leaf area (cm^2): it was measured just before flowering stage by randomly taking five plants from the destructive sampling rows of each plot using CI-202 leaf area meter.

Leaf area index: was calculated as the ratio of total leaf area per area of land (cm^2) occupied by the plant.

Number of effective nodules per plant: effective nodules were identified by their pink color when dissected from non-effective nodules. Then they were determined by counting from five randomly taken plants using destructive sampling in a row per plot at 50% flowering stage. Nodulation score was recorded on a 0-4 scale, where 0 indicates no nodule per plant and 4 indicate more than 30 nodules per plant from the aforementioned selected plants per plot.

Plant height: was measured from the ground level to the tip of plant at physiological maturity from 10 randomly selected plants per plot.

Number of total tillers/plant: all tillers of a plant with pod and without pods were counted from net plot.

3.5.2. Yield components and yield of faba bean component

Pods/plant: total number of pods per plant was counted at maturity from 10 randomly taken plants per plot.

Seeds/pod: average number seeds per pod were counted at harvesting from 10 randomly taken plants per plot.

Stand count: the initial plant stand count was recorded after establishment and at harvest per net plot area when the plant attains maturity and the percentage survival was calculated.

Biological yield (kg/ha): above ground dry biomass was determined from plants harvested from the net plot area after sun drying to a constant weight and converted to kg per hectare.

Seed yield (kg/ha): was obtained from each plot to estimate grain yield kg/ ha. It was weighed and adjusted to 10% moisture content. Grain yield (kg/ ha) at 10% moisture base = yield obtained (kg ha^{-1}) X $\frac{(100-\%\mathrm{mc})}{(100-\%MC)}$; where, mc=Measured grain moisture content (%) and MC=the standard moisture content (10%) (Hong and Ellis, 1996).

Grain moisture content was determined by using seed moisture tester instrument (Model PL-10-860 Olszyn, Owocowa 17).

Harvest Index (HI): were calculated on a plot basis, as the ratio of dried grain weight adjusted to 10% moisture content to the dried total above ground biomass weight and multiplied by 100.Seed moisture content was determined using seed moisture tester instrument. Then the grain yield of each treatment was adjusted to the standard moisture level by computing the conversion factor for each treatment to get the adjusted yield using the following formula (Biru, 1979). Adjusted yield=C.F*Plot yield. **Conversion factor (C.F) =** $\frac{100-Y}{100-X}$ where Y is actual moisture content and X is the standard moisture content to which the yield is to be adjusted (for legumes the standard moisture content is 10) where, mc=Measured grain moisture content (%) and MC=the standard moisture content (10%).

Thousand grain weight (gm): the weight of 1000 seeds was determined by carefully counting the grains, adjusting to 10% moisture content and weighing them using a sensitive balance.

3.5.3. Phenological and growth parameters for wheat component

Days to 50% heading: the number of days from date of sowing to the stage when 50% of the spikes have fully emerged was recorded.

Days to 90 % physiological maturity: the number of days from date of sowing to the stage when 90% of the plants in the plot reached physiological maturity was recorded.

Days to grain filling: the number of days taken from heading to maturity was recorded.

Plant height (cm): was measured from the ground level to the tip of spike at physiological maturity.

3.5.4. Yield components and yield of wheat component

Number of tillers: were counted from two randomly taken rows of 0.5m in length from the net area per plot at physiological maturity.

Number of productive tillers: the number tillers bearing spikes were counted for each plant at physiological maturity from randomly taken rows of 0.5m in length.

Number of kernels per spike: was counted from ten random spikes in a net plot.

Thousand kernel weight (gm): The weight of 1000 kernels was determined by carefully counting the grains, adjusting to 12.5% moisture content and weighing them using a sensitive balance.

Biological yield (kg/ ha): above ground biomass per net plot was determined and converted to hectare.

Grain yield (kg ha^{-1}): grain yield was obtained from each plot to estimate grain yield in kg ha^{-1}. It was weighed and adjusted to 12.5% moisture content.

Grain Yield (kg ha^{-1}) at 12.5% moisture base = yield obtained (kg ha^{-1}) x$\frac{(100-\%\mathrm{mc})}{(100-\%MC)}$, where, mc=Measured grain moisture content (%) and MC=the standard moisture content (12.5%) (Hong and Ellis, 1996).

Harvest index (HI%): was calculated on a plot basis, as the ratio of dried grain weight adjusted to 12.5% moisture content to the dried total above ground biomass weight and multiplied by100. Seed moisture content was determined using seed moisture tester instrument. Then the grain yield of each treatment was adjusted to the standard moisture level by computing the conversion factor for each treatment to get the adjusted yield using the following formula (Biru, 1979):

Conversion factor (C.F) = $\frac{100-\mathrm{Y}}{100-\mathrm{X}}$ where Y is actual moisture content and X is the standard moisture content to which the yield is to be adjusted (for cereals the standard moisture content is 12.5%) where, mc=Measured grain moisture content (%) and MC=the standard moisture content (10%).

Adjusted yield = C.F * Plot yield

Land equivalent ratio: to evaluate productivity and profitability of land, Land Equivalent Ratio (LER) of the crops was estimated as: LER $=L_a + L_b = Y_a/S_a + Y_b/S_b$ where L_a and L_b=

the LERs for individual crops in the mixture and Y_a and Y_b = the individual crop yields in an intercropping situations, S_a and S_b= the yield of species a and b as sole crops (Willey, 1979).

Gross monetary value: gross monetary value was calculated to estimate the economic advantage of inter cropping as compared to sole cropping. It was calculated from the yield of faba bean and wheat by multiplying yields of the component crops by their respective market price. During harvesting period the price of faba bean was 25 Ethiopian birr per kilogram and the price of wheat was 14 Ethiopian birr per kilogram at Asella town.

3.6. Data Analysis

The collected data was subjected to analysis of variance (ANOVA) using SAS software version 9.0(SAS Institute Inc.2004). Significant difference among treatment means were assessed using the least significant difference (LSD) at 5% level of probability (Gomez and Gomez, 1984).

4. RESULTS AND DISCUSSION

4.1. Soil Physico-Chemical Properties of the Experimental Site

4.1.1. Soil Physico-Chemical Properties of the Experimental Site before Planting

The result of soil analysis showed that the soil texture at the trial site was sandy clay loam with bulk density of 1.36 gm/cm^3. It had a pH value of 5.5 (strongly acidic) and organic matter 3.9%, (medium organic matter content according to Tekalign (1991) rate). Total nitrogen 0.13% (low total nitrogen as per Havlin *et al*.(1999) and soil available phosphorus 10.9mg/ kg (medium level of available phosphorus as per bray *et al.* (1945)).

4.1.2. Soil Physico-Chemical Properties of the Experimental Site after Harvesting

Post harvest soil analysis result indicated that main effects of varieties and planting ratio had no significant effect on total nitrogen (N), organic carbon (OC) and organic matter (OM). However, pH value showed highly ($p<0.01$) significant difference for main effects of varieties, but neither for the planting ratio nor the interaction effects (Appendix Table 2). The highest pH value (5.65) was recorded on variety Tumsa (Table 2). Available phosphorus (P) was significantly ($p<0.05$) affected by main effects of varieties, planting ratio and their interaction (Appendix Table 2). The highest available phosphorus (18.38mg/kg) was recorded by variety Hachalu with 1W:2FB planting ratio (Table 3).This is associated with the capability of faba bean to mobilize fixed phosphorus by secretion of acids from its roots. In agreement with this Messaoudi *et al.* (2020) reported that available phosphorus in the soil was higher in faba bean /wheat intercropping.

Table 3. Main effects of varieties and planting ratio on soil pH of the experimental site after harvesting

Varieties	pH
Hachalu	5.48b
Tumsa	5.65a
Ashebeka	5.50b
LSD(0.05)	0.05
Planting ratio	
Sole FB	5.56
1W:1FB	5.55
1W:2FB	5.55
2W:1FB	5.52
LSD(0.05)	NS
CV(%)	1.06

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Table 4. Interaction effect of varieties and planting ratio on soil available phosphorus at experimental site after harvesting

Planting ratio	Varieties		
	Hachalu	Tumsa	Ashebeka
Sole FB	14.32^{abcd}	15.07^{abcd}	13.45^{abcde}
1W:1FB	13.99^{abcde}	17.01^{abc}	12.10^{cde}
1W:2FB	18.38^{a}	12.75^{bcde}	9.25^{e}
2W:1FB	17.16^{ab}	11.41^{de}	14.39^{abcd}
LSD (0.05)	5.01		
CV(%)	20.98		

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

4.2. Plant Tissue Sampling and Analysis for Nitrogen Content

Wheat straw nitrogen content was highly significant ($p<0.01$) for interaction effects of varieties and planting ratio. Significantly highest nitrogen in wheat straw (2.70%) was recorded at variety Hachalu with 1W:1FB planting ratio followed by (2.62%) at variety Ashebeka with 1W:2FB planting ratio. The lowest wheat straw nitrogen content (1.87%) was obtained at variety Tumsa with 1W:1FB planting ratio (Table 4).In general, increasing faba bean ratio with decreasing of wheat ratio has increased wheat straw nitrogen content. This is the result of nitrogen fixation by faba bean and decreased competition of wheat for nitrogen. Despite similar agro ecological recommendations of varieties, minor genotypic variability might be attributed to increased wheat straw nitrogen content under intercropping conditions with faba bean, besides to favorable rain fall distribution.

Table 5. Interaction effect of varieties and planting ratio on wheat straw nitrogen content after harvesting

Planting ratio	Varieties		
	Hachalu	Tumsa	Ashebeka
1W:1FB	2.70^{a}	1.87^{e}	2.23^{d}
1W:2FB	2.35^{cd}	2.44^{bc}	2.62^{ab}
2W:1FB	2.03^{e}	1.92^{e}	1.99^{e}
LSD (0.05)	0.18		
CV(%)	4.70		

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

4.3. Faba Bean Component

4.3.1. Stand count

Stand count at establishment was highly significantly ($P<0.01$) affected by main effects of varieties but neither by planting ratios nor by interaction effects (Appendix Table 3). The highest seedling of faba bean (34.4) was recorded from variety Hachalu while the lowest seedling of faba bean (28.5) was recorded from variety Ashebeka (Table 3). The highest seedling that was recorded from Hachalu plot may be because of the least thousand kernel weight of the variety which increases the number of seeds per a given weight. When planting ratios are compared similar seedling numbers of faba bean was recorded. This indicates that planting ratio of wheat intercropped in faba bean has no effect on stand count of faba bean. Getachew *et al*. (2008) reported the same result in wheat/faba bean intercropping. Similar result was recorded by Teshome *et al.* (2016) in which population density of soybean intercropped in maize had no effect on stand count of maize.

4.3.2. Phenology

Days to 50% flowering of faba bean was significantly ($P<0.05$) affected by main effects of varieties but neither by planting ratios nor by interaction effect (Appendix Table 3). Days to 90% maturity of faba bean was highly significantly ($P<0.01$) affected by main effects of varieties and significantly affected by planting ratios ($P<0.05$) (Appendix Table 3).Variety Tumsa was significantly late than other varieties (Table 5). Varietal difference of days to maturity relates to their genotypic difference. Planting ratio of 2W:1FB significantly enhanced days to maturity of faba bean (Table 5). Both days to flowering and days to maturity of faba bean was not significantly affected by interaction effects of varieties and planting ratio (Appendix Table 3). Increasing wheat ratios intercropped in faba bean has accelerated faba bean maturity. This is because of wheat competition for nitrogen which extends vegetative period. This has increased days to maturity of faba bean. Whereas planting ratio do have an effect on either of the component crops with regard to intra and inter induced interaction and competition among plants.

Table 6. Main effects of varieties and planting ratio on stand count (SC), days to 50% flowering (DF) and days to 90% maturity (DM) of faba bean at Kulumsa in 2019 main cropping season

Varieties	SC	DF	DM
Hachalu	34.4[a]	48.8[b]	138.5[b]
Tumsa	29.1[b]	50.2[a]	147.6[a]
Ashebeka	28.5[b]	49.2 [b]	138.3[b]
LSD(0.05)	2.07	0.64	1.30
Planting ratio			
Sole FB	31.8	49.7	142.1[a]
1W:1FB	30.5	49.1	141.8[a]
1W:2FB	30.4	49.7	142.1[a]
2W:1FB	30.0	49.1	140.0[b]
LSD(0.05)	NS	NS	1.50
CV(%)	7.30	1.55	1.08

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

4.3.3. Growth parameters

Leaf area and leaf area index

Leaf area (LA) was not significantly affected by variety and planting ratio but significantly ($P<0.05$) affected by interaction effects (Appendix Table 3). The highest LA (1162.9cm^2) was recorded from variety Tumsa when planted as sole crop (Table 6). Leaf area index (LAI) of faba bean was not significantly affected by both main effects of varieties and planting ratios. LAI was significantly ($P<0.05$) affected by interaction effect (Appendix Table 3). The highest leaf area index of faba bean (2.9) was recorded from variety Tumsa when planted as sole (Table 7).The highest leaf area and leaf area index at sole planting were due to the highest faba bean plant density and no competition of wheat at this treatment. As a general a better leaf area and leaf area index recorded might be due to indeterminate growth habit of faba bean that might have favored leaf growth and absorption of solar radiation in this late maturing variety. The higher the leaf area, the better could be the ground cover and retained more moisture to accumulate and partition more dry matter to the plant under sole crop as compared to inter plant competition under intercropping condition.

Plant height

Analysis of variance indicated that plant height (PH) was not significantly affected neither by main effects of varieties and planting ratio nor by their interaction effects (Appendix Table 4). Partitioning of dry matter in late maturing variety Tumsa consumed more resources than Hachalu and Ashebeka varieties for vegetative growth such as plant height. In agreement with this Yirga and Zinabu (2019) reported that there was no significant difference for plant height among faba bean varieties for plant height.

Number of tillers per plant

Number of total tillers per plant (NTTPP) of faba bean was not significantly affected by main effect of varieties but highly ($P<0.01$) significantly and significantly ($P<0.05$) affected by planting ratios and interaction effects, respectively (Appendix Table 4). Bakry *et al.* (2011) reported that faba bean tillers per plant were not significantly affected by varieties. Variety Tumsa gave the highest number of total tillers per plant (2.7tillers/plant) when planted sole followed by sole Hachalu (2.5 tillers/plant) (Table 8).As number of wheat rows in faba bean increases tillers/plant decreases. This might be the result of intercrop competition for nutrient, moisture and space that result in lower NTTPP. Getachew *et al*. (2008) also got the same results in wheat faba bean mixed intercropping.

Number of effective nodules per plant

Number of effective nodules per plant (NOENPP) was not significantly affected neither by main effects of varieties and planting ratio nor by interaction effects (Appendix Table 4).

Table 7. Interaction effects of varieties and planting ratio on leaf area of faba bean intercropped with bread wheat

	FB Varieties		
Planting ratio	Hachalu	Tumsa	Ashebeka
Sole FB	1101.8^{abc}	1162.9^{a}	726.7^{cd}
1W:1FB	993.1^{abcd}	653.2^{d}	744.3^{cd}
1W:2FB	712.0^{d}	1029.4^{abcd}	853.2^{abcd}
2W:1FB	768.1^{cd}	857.4^{abcd}	1138.3^{ab}
LSD (0.05)		384.70	
CV(%)		25.38	

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Table 8. Interaction effects of varieties and planting ratio on leaf area index (LAI) of faba bean intercropped with bread wheat

Planting ratio	FB Varieties		
	Hachalu	Tumsa	Ashebeka
Sole FB	2.7^{abc}	2.9^{a}	1.8^{cd}
1W:1FB	2.4^{abcd}	1.6^{de}	1.8^{cd}
1W:2FB	1.7^{d}	2.5^{abcd}	2.1^{abcd}
2W:1FB	1.9^{bcd}	2.1^{abcd}	2.8^{ab}
LSD (0.05)	0.96		
CV(%)	25.35		

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Table 9. Interaction effect of varieties and planting ratio on total tillers per plant of faba bean

	FB Varieties		
Planting ratio	Hachalu	Tumsa	Ashebeka
Sole FB	2.5[ab]	2.7[a]	2.2b[cd]
1W:1FB	1.9[cde]	1.3[f]	1.8[e]
1W:2FB	1.9[cde]	2.1[bcde]	2.3[bc]
2W:1FB	1.9[cde]	1.7[ef]	1.8[de]
LSD (0.05)		0.40	
CV(%)		11.77	

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

4.3.4. Yield Components and Yield of Faba Bean

Number of pods per plant and seeds per pod

Analysis of variance revealed that number of pods per plant showed highly significant ($P<0.01$) difference with respect to main effects of varieties (Appendix Table 4). This result agreed with the result of Merkine and Teshome (2018) who reported significant difference of faba bean pods per plant among varieties. But pods per plant were not significantly affected by planting ratios and the interaction effects (Appendix Table 4). In line with this Getachew *et al*. (2008) reported that there was no significant difference of pods per plant of faba bean when intercropped with wheat. The highest NPPP (17.7) were obtained from variety Hachalu while the lowest PPP (12.9) were obtained from variety Ashebeka (Table 9). This might be due to efficient utilization of moisture in Hachalu under extended rainfall pattern relatively to Ashebeka. Actually, Ashebeka has slightly lower tendency to mid altitude agro ecology to that of the highland adapted variety Hachalu.

Seeds per pod were also not significantly affected by main effects of varieties, planting ratio and interaction effects (Appendix Table 4). This result is similar with the report of previous studies (Ashenafi and Mekuria, 2015). Likewise Merkine and Teshome (2018) reported that there was no significant difference of seeds per pod of faba bean between faba bean varieties.

Table 10. Main effects of varieties and planting ratio on number of pods per plant (PPP) of faba bean

Varieties	PPP
Hachalu	17.7a
Tumsa	13.9b
Ashebeka	12.9b
LSD(0.05)	2.05
Planting ratio	
Sole FB	13.2
1W:1FB	14.9
1W:2FB	16.3
2W:1FB	14.9
LSD(0.05)	NS
CV(%)	16.29

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Thousand seed weight

Thousand seed weight (TKW) of faba bean was highly ($P<0.01$) significant for main effect of varieties, but not for planting ratios and their interaction effects (Appendix Table 5). The highest mean TKW (858.7gm) was recorded in variety Ashebeka whereas the lowest TKW of 698.4g was obtained from variety Hachalu (Table 10). Eventhough thousand seed weight were not significantly affected by planting ratios, the highest TKW of 794.8g were recorded at sole planting among planting ratios (Table 10). This could be due to low inter row competition for nutrient and water in row spaced sole cropped faba bean. In agreement with this Getachew *et* *al*. (2008) reported that thousand seed weight of wheat was not significantly affected under different seed rates of faba bean intercropped in wheat. Thousand seed weight of faba bean decreases as the number of rows of wheat intercropped in faba bean increases in relation with competition effect of inter cropped crops.

Grain yield

The results of analysis showed that there was no significant effect of varieties and interaction effects on grain yield of faba bean but planting ratio showed highly ($P<0.01$)significant effect on faba bean yield (Appendix Table 5). Similarly Merkine and Teshome (2018) reported that faba bean did not show significant difference for grain yield among varieties. On the contrary, Ashenafi and Mekuria (2015) reported that there was a variation between varieties for most yield and yield components including grain yield. Planting ratio of 1W:2FB gave the highest grain yield (3426.0kg ha^{-1}) of faba bean followed by sole planting of faba bean (3393.8kg ha^{-1}). The lowest grain yield (2487.8kg ha^{-1}) was obtained when faba bean was intercropped with 2W:1FB planting ratio (Table 10). This could be due to efficient utilization of growth resources (nutrients, moisture and space) under higher plating ratio of inter cropped faba bean. This might suggest that with increasing rows of faba bean under intercropping condition with wheat gave better yield whenever the growing conditions are satisfied. Likewise Klimek-Kopyra *et al*. (2015) reported that faba bean yield was significantly affected by seeding rate of naked oat and the highest yield of faba bean was recorded when faba bean was intercropped with least seed rate of naked oat. Increasing wheat rows in faba bean decreased its grain yield. Getachew *et al*. (2008) stated that growing of faba bean as a companion crop with wheat reduced the productivity of wheat and vice-versa.

Above ground biomass

The analysis of variance indicated that there was no significant effect of varieties on above ground biomass (AGBM) of faba bean (Appendix Table 5). In line with this Tekle *et al*. (2015) reported that there was no significant variation between faba bean varieties for biological yield. In contrary, Abdalla *et al*. (2015) reported that dry biomass varied among faba bean varieties. Above ground biomass was highly ($P<0.01$) significant for planting ratios (Appendix Table 5). Unlike grain yield, sole planted faba bean gave significantly ($P<0.05$)

highest AGBM (11257.3kg ha^{-1}) of followed by 1W:2FB ratio (10029.2 kg ha^{-1}). The lowest AGBM (7631.6kg ha^{-1}) was obtained when faba bean was intercropped with 2W:1FB planting ratio (Table 10). Generally, extended rain fall distribution increased the biomass obtained as faba bean has indeterminate growth habit either in sole or in intercropped faba bean with wheat.

Harvest index

Harvest index (HI) was highly significantly ($P<0.01$) affected by main effects of varieties and planting ratios as well as interaction effects of varieties and planting ratios (Appendix Table 5). The highest HI (36.0%) was recorded by variety Hachalu and at 1W:1FB planting ratio followed by Ashebeka at 1W:1FB planting ratio (34.6%). Lowest HI (26.8%) was recorded at Ashebeka when planted sole (Table 11). This could be related to inherent characteristics of the varieties and rain fall distribution. Ashenafi and Mekuria (2015) reported that harvest index of faba bean had been significantly affected by faba bean varieties. Better HI means better yield efficiency of the plant under the given management practices.

Table 11. Main effects of varieties and planting ratio on thousand kernel weight (TKW (g)), grain yield (GY (kg ha^{-1})), above ground biomass (AGBM (kg ha^{-1})) and harvest index (HI %) of faba bean

Varieties	TKW (g)	GY(kg ha^{-1})	AGBM(kg ha^{-1})
Hachalu	698.4^{c}	3190.1	9342.0
Tumsa	792.3^{b}	3018.9	9364.1
Ashebeka	858.7^{a}	2969.5	9429.9
LSD(0.05)	36.89	NS	NS
Planting ratio			
Sole FB	794.8	3393.8^{a}	11257.3^{a}
1W:1FB	789.5	2930.3^{b}	8596.6^{b}
1W:2FB	790.4	3426.0^{a}	10029.2^{a}
2W:1FB	757.7	2487.8^{c}	7631.6^{b}
LSD(0.05)	NS	419.85	1289.0
CV(%)	5.56	14.04	14.05

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Table 12. Interaction effect of varieties and planting ratio on harvest index of faba bean

Planting ratio	FB varieties		
	Hachalu	Tumsa	Ashebeka
Sole FB	33.3ab^{cd}	30.5^{d}	26.8^{e}
1W:1FB	36.0^{a}	31.4^{bcd}	34.6^{a}
1W:2FB	34.1^{ab}	33.9^{ab}	34.4^{a}
2W:1FB	33.2^{abcd}	33.4^{abc}	30.9^{cd}
LSD (0.05)	2.78		
CV(%)	5.02		

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

4.4. Wheat Component

4.4.1. Phenology

Days to heading, days to grain filling and days to maturity of wheat were not significantly affected by both main effect of varieties and planting ratio (Appendix Table 6). Only days to grain filling were significantly ($P<0.05$) affected by the interaction effect of varieties and planting ratio (Appendix Table 6). The highest grain filling days (84.0 days) was recorded when Hachalu and Tumsa were planted in 1W:1FB and 1W:2FB planting ratios respectively. The earliest grain filling (80.6) was recorded when Hachalu was planted in 2W:1FB planting ratio (Table 13). When sole planted and intercropped wheat are compared days to heading, days to grain filling and days to maturity were highly ($P<0.01$) significantly affected (Appendix Table 6). Sole cropped wheat was earlier than intercropped wheat by days to heading, days to grain filling and days to maturity of wheat (Table 12). This might be the result of shading effect of faba bean on wheat and nitrogen delivered to wheat during the growing period. (Ghiles *et al*., 2018) reported that intercropping increases availability of soil-N for wheat. This increase may be due to a lower interspecific competition between legume and wheat than intra-specific competition between wheat plants and fixation of the atmospheric nitrogen. As nitrogen availability increases days to maturity of wheat increased (Sher *et al*., 2018).

Table 13. Effects of Cropping system on days to 50% heading(DH), days to grain filling (DGF) and days to 90% maturity (DM) of wheat

Cropping system	DH	DGF	DM
Sole cropped	70.0[b]	76.0[b]	146.0[b]
Intercropped	72.3[a]	82.3[a]	154.7[a]
LSD(0.05)	0.18	1.23	1.32
CV(%)	0.07	0.44	0.24

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Table 14Table 13. Interaction effects of varieties and planting ratio on days to grain filling of wheat

	FB Varieties		
Planting ratio	Hachalu	Tumsa	Ashebeka
1W:1FB	84.0[a]	83.0[abc]	81.6b[cd]
1W:2FB	81.0[cd]	84.0[a]	82.6[abcd]
2W:1FB	80.6[d]	82.6[abcd]	83.3[ab]
LSD (0.05)	2.23		
CV(%)	1.56		

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

4.4.2. Growth Parameters

Tillers

Total tillers per plant (TTPP) and productive tillers per plant (PTPP) were not significantly affected by main effects of varieties, intercropping ratios, interaction and cropping system (Appendix Table 7).

Leaf area, leaf area index and plant height

Plant height of wheat was not significantly affected by main effect of varieties, interaction and cropping system but significantly ($P<0.05$) affected by planting ratio (Appendix Table 7). The tallest (82.6cm) and shortest (79.8cm) plant height of wheat was recorded at 2W:1FB and 1W:2FB respectively (Table 14).

Table 15. Main effects of varieties and planting ratio on plant height (PH) and leaf area index (LAI) of wheat

Varieties	PH	LAI
Hachalu	81.6	1.7
Tumsa	81.8	2.0
Ashebeka	80.3	1.6
LSD(0.05)	NS	NS
Planting ratio		
1W:1FB	81.3[ab]	1.9[a]
1W:2FB	79.8[b]	1.0[b]
2W:1FB	82.6[a]	2.4[a]
LSD(0.05)	2.07	0.74
CV(%)	2.55	40.8

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Leaf area was not significantly affected by main effect of varieties, intercropping ratios, interaction and cropping system (Appendix Table 7). Leaf area index (LAI) of wheat was also not significantly affected by main effect of varieties, interaction and cropping system, but highly significantly ($P<0.01$) affected by main effect of intercropping ratios (Appendix Table 7). Highest (2.4) and lowest (1.0) LAI were recorded at 2W:1FB and 1W:2FB respectively (Table 14). The LAI due to 1W:2FB was significantly lower than that of 1W:1FB and 2W:1FB. This occurred as a result of population density difference leading to aerial resource competition.

4.3.3. Yield components and yield of wheat

Number of kernels per spike

Number of kernels per spike (NKPS) was not significantly affected by main effect of varieties and interaction but highly significantly ($P<0.01$) affected by planting ratio (Appendix Table 8).Similar results of kernels per spike of wheat were counted and recorded among the different faba bean varieties. This implies that faba bean varieties had no effect on kernels per spike. Planting ratio 2W:1FB gave the highest kernels per spike (41.5) while the lowest (36.0) kernels per spike were recorded at 1W:1FB planting ratio (Table 15). No significant difference was observed among intercropped and sole planted wheat for kernels per spike (Appendix Table 8).

Thousand kernel weight

Thousand kernel weight (TKW) was none significantly affected by faba bean varieties and interaction effects whereas, planting ratio had highly ($P<0.01$) significant effect on TKW of wheat (Appendix Table 8). None significant difference was observed in TKW of maize intercropped with different common bean varieties (Tamado *et al.*, 2007). The highest TKW of wheat (38.7g) was recorded in 1W:2FB planting ratio. The minimum TKW of wheat (35.5g) was observed at 2W:1FB (Table 15). In comparing sole cropped to intercropped wheat, TKW was significantly affected by cropping system (Table 15). This study indicates that when competition for resources is increased TKW showed gradual decrease.

Table 16. Main effects of varieties and planting ratio on kernels per spike (NKPS) and thousand kernel weight (TKW (gm) of wheat

Varieties	NKPS	TKW(g)
Hachalu	39.2	37.4
Tumsa	38.3	37.2
Ashebeka	39.5	37.3
LSD(0.05)	NS	NS
Planting ratio		
1W:1FB	36.0b	38.0[a]
1W:2FB	39.5a	38.7[a]
2W:1FB	41.5a	35.5[b]
LSD(0.05)	2.60	0.77
CV(%)	6.68	2.08
Sole cropped versus intercropped		
Cropping system		
Sole cropped		39.9[a]
Intercropped		37.4[b]
LSD(0.05)		2.30
CV(%)		1.70

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Grain yield

The analysis result revealed that planting ratio showed highly (P<0.01) significant difference in grain yield, but main effects of varieties and their interaction effects did not (Appendix

Table 8). Planting ratio of 2W:1FB gave the highest wheat grain yield (1896.6kg ha^{-1}). The lowest wheat grain yield (711.3kg ha^{-1}) was recorded in 1W:2FB planting ratio. The mixture with a higher sharing of wheat (2W:1FB) achieved a highly significantly higher yield regardless of the type of variety (Table 16). This attributed to the highest population density of wheat at 2W:1FB planting ratio which allowed better resource use efficiency. The same bread wheat variety Hulluka was intercropped with different varieties of faba bean so that the same yield of 1343.5kg ha^{-1} was obtained (Table 16). This indicates that faba bean varieties had no varietal effect on intercropped wheat grain yield. Practically, sole wheat outsmarted intercropped wheat as it has high solar absorption efficiency and low intercrop competition. When number of rows of intercropped wheat increased grain yield of wheat was also increased. Klimek-Kopyra *et al.* (2015) reported that the highest grain yield of faba bean was obtained from highest seed rate of faba bean in in faba bean naked oat intercropping. Klimek-Kopyra *et al.* (2015) further reported that the highest grain yield of faba bean 1.57 ton per hectare was recorded at 75:25 faba bean/naked oat cropping ratio. Similarly, Getachew *et al*. (2008) gained significant difference of wheat grain yield in wheat and faba bean mixed intercropping. He described that the highest grain yield of wheat (3601 $kgha^{-1}$) was observed at the lowest seeding rate sharing of faba bean (100:12.5 wheat/faba bean).

Above ground biomass

The results of analysis showed that above ground biomass (AGBM) yield was not significantly affected by main effects of varieties and interaction effect but highly ($P<0.01$) significantly and significantly affected by main effects of inter-cropping ratio and cropping system respectively (Appendix Table 8). The highest (8057.1$kgha^{-1}$) and the lowest (3154.9$kgha^{-1}$) AGBM yield of wheat was recorded in 2W:1FB and 1W:2FB plating ratios, respectively (Table 16). The higher seeding rate of wheat resulted in greater above ground biomass yield than the lower seeding rate of wheat. In addition to this wheat was seriously affected by shading effect of faba bean which decreases wheat performance. The AGBM yield of sole planting was significantly higher than the intercropped (Table 16). Teshome *et al.* (2015) reported that there was significant difference of AGBM yield of soybean in soybean maize intercropping and the higher seeding rate treatment gave the significantly greater AGBM yield of soybean. Likewise, Biruk (2007) reported that biological yield of bean increased as plant population increased under sorghum /bean intercropping.

Table 17. Main effects of varieties and planting ratio on grain yield (GY), above ground biomass (AGBM) and harvest index (HI) of wheat

Varieties	GY(kg ha^{-1})	AGBM (kg ha^{-1})	HI (%)
Hachalu	1343.5	4852.2	30.2^{a}
Tumsa	1343.5	6115.8	22.2^{b}
Ashebeka	1343.5	4805.0	28.9^{a}
LSD(0.05)	NS	NS	6.65
Planting ratio			
1W:1FB	1422.6b	4560.9b	32.7^{a}
1W:2FB	711.3c	3154.9b	23.8^{b}
2W:1FB	1896.6a	8057.1a	24.8^{b}
LSD(0.05)	120.6	1535.7	6.65
CV(%)	8.98	29.22	24.53
Sole cropped versus intercropped			
Cropping system			
Sole cropped	4268.0^{a}	10088^{a}	42.1^{a}
Intercropped	1343.5^{b}	5258^{b}	27.1^{b}
LSD(0.05)	1693.4	3747.9	6.84
CV(%)	17.18	13.90	5.62

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

Harvest index

Harvest index (HI) of wheat was significantly (P<0.05) affected by variety, planting ratio and cropping system but, not by their interaction effects (Appendix Table 8). The highest HI (32.7%) was obtained from 1W:1FB and the lowest wheat harvest index (23.8%) were obtained from 1W:2FB (Table 16). This could be related to late maturing nature of the variety whereby it consumes more time to accumulate more dry matter. The highest HI recorded in1W:1FB planting ratio might be due to the high grain yield to biomass as a result of high partitioning of dry matter to the grain.

4.5. System Productivity

4.5.1. Land Equivalent Ratio (LER)

Differences among faba bean varieties were not significant for all the three (partial LER of faba bean, partial LER of wheat and total LER) land equivalent ratios (Appendix Table 9). Faba bean varieties did not show any influence on partial land equivalent ratio of wheat. Differences among planting ratios were highly (P<0.01) significant for both partial LER of faba bean and partial LER of wheat (Appendix Table 9). The highest partial LER of faba bean (1.11) and partial LER wheat (0.44) was recorded at 1W:2FB and 2W:1FB, respectively (Table 17). As the ratio of intercropped wheat increased PLERW and PLERFB increased and decreased, respectively. Total land equivalent ratio (TLER) was significantly affected by planting ratios (Appendix Table 9).Statistically highest TLER was registered in 1W:1FB (1.21) and 1W:2FB (1.27) for efficient utilization of growth resources. Highest TLER (1.27) was obtained from 1W:2FB intercropping ratio and lowest TLER (1.00) were recorded in sole faba bean (Table 9). A 21% and 27% additional yield advantage were obtained at1W:1FB and 1W:2FB planting ratios than planting sole crop, respectively. So it seems optimistic in for resource poor and small land holding farmer. As the ratio of faba bean decreased total land equivalent ratio decreased. In line with this Nargis *et al*. (2004) reported that total land equivalent ratio decreased from1.17 to 1.12 when planting ratio was changed from 1W:1L to1W: 3L in wheat /lentil intercropping.

Table 18. Effect of varieties and planting ratio on partial land equivalent ratio of faba bean (PLERFB), partial land equivalent ratio of wheat (PLER W) and total land equivalent ratio (TLER)

Varieties	PLERFB	PLER W	TLER
Hachalu	0.85	0.31	1.09
Tumsa	0.99	0.31	1.22
Ashebeka	0.95	0.31	1.18
LSD(0.05)	NS	NS	NS
Planting ratio			
Sole FB	1.00[ab]	-	1.00[b]
1W:1FB	0.88[bc]	0.33[b]	1.21[a]
1W:2FB	1.11[a]	0.16[c]	1.27[a]
2W:1FB	0.73[c]	0.44[a]	1.18a
LSD(0.05)	0.19	0.0001	0.19
CV(%)	21.16	0.02	16.89
Sole cropped versus intercropped			
Cropping system			
Sole cropped	1.00[a]		
Intercropped	0.31[b]		
LSD(0.05)	0.02		
CV(%)	1.22		

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

4.5.2. Gross Monetary Value

Gross monetary value (GMV) was significantly ($P<0.05$) affected by interaction effects of faba bean varieties and planting ratio (Appendix Table 10). The highest gross monetary value (100591 ETB/ha) was obtained from planting ratio of 1W:2FB with variety Tumsa. Variety Hachalu when planted at 1W:2FB yielded 98,417 ETB/ha. GMV of 96,854 ETB/ha was gained when Ahebeka was planted at 1W:2FB planting ratio. Sole wheat gave the lowest gross monetary value which was 59,752 ETB/ha (Table 18). Thus, 18.5% and 40% additional income can be gained than planting sole faba bean and wheat, respectively. This could be due to high price and better competition ability of faba bean with good rain fall distribution in the growing season. Nevertheless, irrespective of faba bean varieties, 1W:2FB planting ratio could be tentatively recommended in the area. However, further economic analysis might be necessary in calculating the actual yield benefit of intercropping from this trial.

Table 19. Effect of varieties and planting ratio on gross monetary value (ETB/ha)

Planting ratio	Hachalu	Tumsa	Ashebeka
Sole FB	93647^{ab}	82694^{ab}	78197^{b}
1W:1FB	98417^{a}	86793^{ab}	94317^{ab}
1W:2FB	89381^{ab}	100591^{a}	96854^{a}
2W:1FB	93993^{ab}	88241^{ab}	84013^{ab}
Sole wheat	59752^{c}		
LSD (0.05)		18239	
CV(%)		12.27	

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation; NS= non-significant. Means in column followed by the same letters are not significantly different at 5% level of Significance.

5. SUMMARY AND CONCLUSIONS

Multiple cropping is the intensification of cropping in time and space dimension. Though non-significant, there was a slight modification on some of the physico-chemical properties of the soil after harvesting for main and interaction effects of verities and planting ratios. On average, available phosphorus was 15.17 mg/kg in intercropping and 11.13 mg/kg in sole planted wheat. Total nitrogen was 0.15 in intercropping and 0.12 in sole planted wheat. The highest available phosphorus (18.38mg/kg) was recorded in variety Hachalu and 1W:2FB planting ratios.

For faba bean component, stand count at establishment and days to 50% flowering were significantly affected by main effects of varieties, but influenced neither by planting ratios nor by interaction effects. Days to 90% maturity was highly significant for main effects of varieties and significantly different for planting ratios. Leaf area and leaf area index was significantly affected by interaction effects of varieties and planting ratios. Number of total tillers per plant was not significantly affected by main effect of varieties, but highly significantly and significantly affected by planting ratios and interaction effects, respectively. Plant height and number of effective nodules per plant was not significantly affected neither by main effects of varieties and planting ratio nor by their interaction effects. Number of pods per plant and thousand seed weight were significant with respect to main effects of varieties, but not for planting ratios and their interaction effects. Grain yield and above ground biomass were highly significant for planting ratios, but not for varieties. Harvest index was highly significantly affected by main effects of varieties, planting ratios as well as interaction effects.

For wheat component, days to heading, days to grain filling and days to maturity of wheat were not significant for both main effects of varieties and intercropping ratios. Days to grain filling were significantly affected by the interaction effect of varieties and planting ratios. Stand count at establishment was not significantly affected by main effect of varieties, but highly significant for planting ratios. Total tillers per plant and productive tillers per plant were not significantly affected by both main effects of varieties and planting ratios. Plant height was not significantly affected by main effect of varieties, but it was significant for planting ratios. Leaf area index was not significant for main effect of varieties, but highly affected by main effect of planting ratios. Number of kernels per spike was not significantly affected by main effect of varieties, but highly affected by planting ratios. Planting ratio had highly significant effect on thousand kernel weight, but not for main effect of varieties. Grain yield and Aboveground biomass yield were highly significant for planting ratio, but not for main effects of varieties.

System productivity in multiple cropping indicated that differences among faba bean varieties were not significant for partial land equivalent ratio of faba bean, partial land equivalent ratio of wheat and total land equivalent ratio. Among varieties, Tumsa gave the higher faba bean partial land equivalent ratio of 0.99. Faba bean varieties did not show any influence on partial land equivalent ratio of wheat. The highest total land equivalent ratio (1.27) was obtained from1W:2FB planting ratio. Gross monetary value was significantly affected by interaction effects of faba bean varieties and planting ratios. The highest gross monetary value, which was 100,591 ETB /ha was obtained with planting ratio of 1W:2FB with Ashebeka variety. Sole wheat gave the lowest GMV of 59, 752 ETB/ha. Nevertheless, irrespective of faba bean varieties, 1W:2FB planting ratio could be tentatively recommended in the area. However, further economic analysis might be necessary in calculating the actual yield and suitability of harvesting to maximize benefit of intercropping from this observation trial.

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7. APPEDICES

Appendix Table 1. Meteorological data of Kulumsa at year 2019.

Month	Rainfall (mm)	Minimum temperature ^{o}C	Maximum temperature ^{o}C
January	0.0	9.2	24.1
February	29.1	10.7	24.6
March	87.2	11.8	27.2
April	25.3	13.5	27.1
May	52.7	13.2	23.9
June	64.2	12.7	24.7
July	164.6	13.0	22.5
August	109.1	12.7	21.9
September	131.1	12.2	21.4
October	12.6	12.6	23.6
November	0.0	11.0	23.4
December	0.0	8.1	22.5
Total	676.6		
Mean		11.7	23.9

Source: Kulumsa Agricultural Research Center

Appendix Table 2. Mean squares of ANOVA for Ph, available phosphorus (P), total nitrogen (N), organic carbon (OC) and organic matter (OM) of soil of experimental site as affected by faba bean varieties and planting ratio

Source of variation	df	Mean squares				
		pH	P	N	OC	OM
Rep	2	0.0004	51.56	7.500E-07	0.01	0.05
Variety	2	0.09***	40.26*	1.527E-04ns	0.04ns	0.13ns
Planting ratio	3	0.003ns	1.68*	2.092E-04ns	0.01ns	0.04ns
Var*SP	6	0.005ns	22.84*	1.489E-04ns	0.12ns	0.36ns
Error	22	0.0034	8.76	1.094E-04	0.05	0.16
CV		1.06	20.98	7.16	10.49	10.48
	Sole cropping versus intercropping					
Rep	2	1.002E-04	23.96	1.362E-04	0.01	0.04
Cropping system	1	1.460E-04NS	16.34ns	5.309E-04	0.005ns	0.01
Error	2	1.773E-04	1.02	5.609E-05	0.001	0.004ns
CV		0.24	7.69	5.35	1.66	1.66

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively

Appendix Table 3. Mean squares of ANOVA for stand count (SC), days to flowering(DF), days to physiological maturity (DM), leaf area (LA) and leaf area index (LAI) of faba bean varieties as affected by planting ratio of intercropped wheat

Source of variation	df	Mean squares				
		SC	DF	DM	LA	LAI
Rep	2	27.65	1.19	6.36	86453.49	0.54
Variety(V)	2	126.36***	6.36*	339.36***	10847.65ns	0.06ns
Planting ratio(PR)	3	5.65ns	1.33ns	9.43*	64949.96ns	0.40ns
V*PR	6	3.11ns	1.13ns	5.54ns	145717.89*	0.90*
Error	22	5.03	0.58	2.36	51615.61	0.32
CV		7.30	1.55	1.08	25.38	25.34

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively

Appendix Table 4. Mean squares of ANOVA number of effective nodules per plant (NENPP), plant height, tillers per plant(TPP), pods per plant (PPP) and seeds per pod (SPP) of faba bean varieties as affected by planting ratio of intercropped wheat

Source of variation	df	Mean squares				
		NENPP	PH	TPP	PPP	SPP
Rep	2	10297.92	50.333	0.05	24.05	0.01
Variety(V)	2	2746.01ns	39.083ns	0.015ns	77.14***	0.004ns
Planting ratio(PR)	3	352.80ns	219.583ns	1.14***	14.17ns	0.03ns
V*PR	6	1438.79ns	82.528ns	0.18*	3.28ns	0.02ns
Error	22	1584.68	121.727	0.05	5.86	0.01
CV		34.59	7.25	11.76	16.29	4.80

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively

Appendix Table 5. Mean squares of ANOVA thousand kernel weight (TKW), days grain yield (GY), above ground biomass (AGBM) and harvest index (HI) of faba bean varieties as affected by planting ratio of intercropped wheat

Source of variation	df	Mean squares			
		TKW	GY	AGBM	HI
Rep	2	19.18	460963.21	2668231.00	2668231.00
Variety(V)	2	778.76***	174673.26ns	25102.08ns	25102.08**
Planting ratio(PR)	3	26.27ns	1360389.43**	22850118.00***	22850118.00***
V*PR	6	6.87ns	136640.88NS	858481.08nsn	858481.08**
Error	22	18.99	192137.01	1738509.8	1738509.8
CV		5.56	14.62	14.05	14.05

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively

Appendix Table 6. Mean squares of ANOVA for stand count (SC), days to heading(DH), days to grain filling and days to physiological maturity (DM) of wheat as affected by faba bean varieties and planting ratio of wheat and cropping system

Source of variation	Df	Mean squares		
		DH	DGF	DM
Rep	2	0.11	0.33	0.11
Variety(V)	2	1.77ns	4.00	0.44ns
Planting ratio(PR)	2	1.77ns	1.00	1.44ns
V*PR	4	2.38ns	6.33*	1.88ns
Error	16	0.86	1.66	0.65
CV		1.28	1.56	0.52
Sole cropping versus intercropping				
Rep	2	0.002	0.12	0.14
Cropping system	1	8.34***	60.30**	113.53**
Error	2	0.002	0.12	0.14
CV		0.07	0.44	0.24

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively

Appendix Table 7. Mean squares of ANOVA for total tillers per plant (TTPP), productive tillers per plant(PTPP), plant height (PH), leaf area (LA) and leaf area index(LAI) of wheat as affected by faba bean varieties and planting ratio of wheat and cropping system

Source of variation	df	Mean squares				
		TTPP	PTPP	PH	LA	LAI
Rep	2	0.42	0.31	10.48	10820.13	1.17
Variety(V)	2	0.73ns	0.93ns	6.37ns	1503.33ns	0.33ns
Planting ratio(PR)	2	2.21ns	0.22ns	17.37*	2084.04ns	4.14**
V*PR	4	0.12ns	0.23ns	5.03ns	1241.27ns	0.17ns
Error	16	0.81	0.30	4.31	3848.80	0.55
CV		15.63	18.25	2.55	35.51	40.87
Sole cropping versus intercropping						
Rep	2	0.20	0.06	4.08	3487.11	2.46
Cropping system	1	0.12ns	1.47ns	18.25ns	1.63ns	6.46ns
Error	2	0.22	0.10	3.61	10453.50	4.30
CV		7.99	12.90	2.28	59.63	72.74

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at 0.01, 1% and 5% level of significant, respectively

Appendix Table 8. Mean squares of ANOVA for number of kernels per spike (NKPS), thousand kernel weight(TKW), grain yield (GY), above ground biomass (AGBM) and harvest index(HI) of wheat as affected by faba bean varieties and planting ratio of wheat and cropping system

Source of variation	df	Mean squares				
		NKPS	TKW	GY	AGBM	HI
Rep	2	4.97	1.25	884569.333	4443431.7	181.30
Variety(V)	2	3.80ns	0.62	0.00ns	4976032.7ns	167.98*
Planting ratio(PR)	2	68.95**	24.61***	3203529.33***	57346827.1***	213.64*
V*PR	4	2.42ns	0.27	0.00ns	538126.4ns	15.91ns
Error	16	6.80	0.6048	14563.33	2361400.9	44.38
CV		6.68	2.08	8.98	29.22	24.53
	Sole cropping versus intercropping					
Rep	2	28.50	0.12	856345	3394152	19.73
Cropping system	1	29.91ns	9.12*	1.28*	3.49*	335.32*
Error	2	11.57	5.07	232349	1138367	3.78
CV		8.17	1.70	17.18	13.91	24.53

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively

Appendix Table 9. Mean squares of ANOVA for partial land equivalent ratio of wheat (PLELW), partial land equivalent ratio of faba bean (PLERFB), and total land equivalent ratio (TLER)

Source of variation	Df	Mean squares		
		PLELW	PLERFB	TLER
Rep	2(2)	5.20	0.01	0.01
Variety(V)	2(2)	3.12ns	0.05ns	0.05ns
Planting ratio(PR)	2(3)	0.17***	0.23**	0.12*
V*PR	4(6)	3.19ns	0.05ns	0.05ns
Error	16(22)	4.27	0.03	0.03
CV(%)		0.02	21.16	16.89

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively

Appendix Table 10. Mean squares of ANOVA gross monetary value

Source of variation	Df	
		GMV
Rep		6.77
Treatment		3.48*
Error		1.17
CV		12.27

Where, ANOVA =Analysis of variance; CV = coefficient of variation, NS= non-significant difference;***, ** and * significant at0.01, 1% and 5% level of significant, respectively