EFFECT OF PLANT SPACING AND HERBICIDE APPLICATION ON WEED INFESTATION, YIELD AND YIELD COMPONENTS OF FABA BEAN (*VICIA FABA L*.) AT DEBRE BERHAN, CENTRAL HIGH LAND OF ETHIOPIA

M.Sc. Thesis

Gashaw Demiss

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Debre Berhan, Ethiopia

EFFECT OF PLANT SPACING AND HERBICIDE APPLICATION ON WEED INFESTATION, YIELD AND YIELD COMPONENTS OF FABA BEAN (*VICIA FABA L.*) AT DEBRE BERHAN

A Thesis Submitted to Department of Plant Science College of Agriculture and Natural Resource Sciences, School of Graduate Studies, Debre Berhan University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Plant Protection

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Major Advisor: Habtamu Kefelegn (Asst. Professor)
Co -Advisor: Bizuayehu Desta (PhD)

June, 2021

Debre Berhan, Ethiopia

SCHOOL OF GRADUATE STUDIES

COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES

DEBRE BERHAN UNIVERSITY

APPROVAL SHEET – I

This is to certify that the thesis entitled: Effect of plant spacing and herbicide application on weed infestation, yield and yield components of faba bean (*Vicia fabaL.*) at Debre Berhan, submitted in partial fulfillment of the requirements for the degree of Master of Science in Plant Protection of the Graduate Program of the Plant Science, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by Gashaw Demiss *Id. No* DBU PGR/162/10, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

Therefore, I recommend that it to be accepted as fulfilling the thesis requirements.

Habtamu Kefelegn (Asst. Professor) __________________ _________________

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Bizuayehu Desta (PhD)__________________ _________________

Name of Co-Advisor Signature Date

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APPROVAL SHEET – II

We, the undersigned members of the board of the examiners of the final open defense by Gashaw Demiss have read and evaluated his thesis entitled Effect of plant spacing and herbicide application on weed infestation, yield and yield components of faba bean (*Vicia fabaL.*) at Debre Berhan, and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Plant Protection.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the department graduate committee (DGC) of the candidate's major department.

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STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for the thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for degree of Master of Science at Debre Berhan University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of my academic degree, diploma, or certificate.

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Date of submission: ________________

BIOGRAPHICAL SKETCH

The author was born in October 21, 1984 in Amhara National Regional State, North Shewa Zone, Merhabete Woreda. He attended his elementary school education at Kolash elementary school from 1992 to1998 and Secondary School education from 1999 to 2002 at Alem Ketema Comprehensive Secondary School and Merhabete Arbegnoch Senior Secondary School. In 2003, he joined Agarfa Agricultural Technical Vocational Education and Training College (ATVET) and graduated with Diploma in Plant Science field of specialization in July 2006 and he had served in Bureau of Agriculture and RuralDevelopment of the Amhara National Regional State, Basona Worana Woreda as Plant Science Expert at community level up to the year 2014.

He has also attended in Wollo University from 2015 to 2017 and graduated with B.Sc. Degree in plant science field of specialization. Soon after graduation he has been served as Supervisor in Bureau of Agriculture and Rural Development of the Amhara National Regional State, Basona Worana Woreda until he joined Debre Berhan University on October 2018 to studyhis Master of Science degree in Plant Protection.

LIST OF ACRONYMS AND ABBREVIATIONS

DBW	Dry Biomass Weight
DIC	Difference in Input Cost Compared with Control
DNI	Difference in Net Income Compared with Control
EIAR	Ethiopian Institute of Agricultural Research
GY	Grain Yield
HI	Harvest Index
HSW	Hundred Seeds Weight
ICARDA	International Centre of Agricultural Research in the Dry Areas
IRR	Internal Rate of Return
LAI	Leaf Area Index
MRR	Marginal Rate of Return
NPPP	Number of pods per Plant
NSPP	Number of Seed per Plant
STBH	Stand before Harvest
STBT	Stand before Thinning
WAE	Week after Emergence

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ABSTRACT

Ethiopia is one of the major faba bean (Vicia faba L.) producing countries in the globe. It is an important pulse crop grown in the highlands of Ethiopia, where the soil and weather are considered to be congenial for better growth and development of the crop. The major problem facing the production of faba bean in Ethiopia are different diseases, insect pests and weeds. Uncontrolled weed populations can substantially reduce the yield of the faba bean production up to 80-90% when they are not removed during critical period of competition. This study was initiated with an objective of evaluating the effect of plant spacing and herbicide application on weed infestation, yield and yield components of faba bean (Vicia faba L.). Three inter and intra row plant spacing (35 cm x 15cm, 40cm x 10cm and 45cm x 5cm) and four weeding options (two times hand weeding, use of Gallant Super and Fusillade herbicides and un-weeding treatment as a control) were used with randomized complete block design in three replications with a factorial arrangement. The application of herbicides significantly reduces grass weeds such as; Snowdenia polystachya, Cyperus sculentus and Avena fatua after application. The interaction effects of plant spacing and weed management practices significantly affected the number of tillers per plant. The highest number of tiller per plant recorded was 2.833 on 35cm x 15cm treated with twice hand weeding management. Faba bean crop attained the maximum height in weedy check plots which was significantly higher than all the other weed management treatments. The number of pods per plant, number of seeds per pod and weight of hundred seeds (gm) were recorded in twice hand weeding plots and again on plots of dimension 35 cm x 15 cm spacing. The highest total dry biomass (14128.27 kg ha^{-1}) and the highest grain yield (6400.97 kg ha^{-1}) were obtained in twice hand weeding with 45cm x 5cm plant spacing. The lowest total dry biomass (4297.40 kg ha^{-1}) and grain yield (1819.53 kg ha^{-1}) were recorded from weedy plot with 35 cm x 15cm spacing. The results indicated that the use of 45 cm x 5 cm inter and intra row spacing in combination with twice hand weeding proved to be the most feasible practice for faba bean production.

***Keywords**: Faba bean, fusillade, gallant super, plant spacing, weeds.*

1. INTRODUCTION

Ethiopia is one of the major faba bean (*Vicia faba* L.) producing countries in the world (FAO, 2015). The country is the fourth largest exporting country next to France, Australia, and the United Kingdom (FAO, 2016). Faba bean takes the largest share of area (443, 966 ha) and production (848, 655 tones) of the pulses grown in Ethiopia (CSA, 2015). The crop usually grows in Nitisol and Vertisol dominated areas of Ethiopia mixed with cereals and field peas. The average national yield of faba bean is about 2.1 t ha^{-1} which is very low compared to the average yield of 3.7 t ha^{-1} in major producer countries (CSA, 2018; Wondafrash *et al*., 2019).

Faba bean (*Vicia faba* L.) plays a key role in improving food and feed security of smallholder farmers and soil fertility (Daba and Sharma, 2018). It is an important pulse crop grown in the highlands (1800-3000 masl) of Ethiopia, where the soil and weather are considered to be congenial for better growth and development of the crop (Dobocha *et al*., 2019). It is said to be a crop of high economic value with its edible seed serving as an essential protein complement in the cereal-based Ethiopian diet, particularly for the poor who cannot afford animal protein (Dobocha *et al*., 2019). Even though the crop plays a significant role for Ethiopian farmers as a source of food, feed, and cash crop, the yield generally is below the world average due to several factors: poor crop management practices, lack of high yielding cultivars, stress inflicted by harsh environmental conditions and poor soil fertility can be listed as some of the causes of low yield (Dobocha *et al*., 2019).

Weeds are plants which compete with crops for nutrients, space, light and exerting a lot of harmful effects by reducing the quality and quantity of the crop if their populations are left uncontrolled (Halford *et al*., 2001; Kavaliauskaite and Bobinas, 2006). The major problems facing the production of faba bean in Ethiopia are different diseases, insect pests and weeds (Daba and Sharma, 2018; Wondafrash *et al*., 2019) and faba bean has low competitive ability for weeds during its early stages of growth (Daba and Sharma, 2018). Uncontrolled weed populations (both broad-leaf and grass weed species) can substantially reduce the yield of the faba bean production up to 80% (Daba and Sharma, 2018) and up to 90% in common bean when they are not removed during critical period of competition (Rezene and Kedir, 2008; Mengesha *et al.*, 2013). The critical period of weed competition varies from 3 to 8 weeks after crop emergence for this crop (EIAR, 2018). Major weeds in faba bean crops are managed with hand weeding or by spraying herbicides (EIAR, 2018). Hand weeding is the major weed control method in pulse production in Ethiopia (Kissi Wakweya and Reta Dargie, 2017). One time early weeding at 25 days after crop emergence resulted in 70% yield increase of common bean compared to no weeding (Rezene and Kedir, 2008). Two times hand weeding is very essential forfaba bean one 3-4 weeks after emergence (WAE) and the second 6-8 WAE (EIAR, 2018)**.** Herbicides also constitute a highly efficient technique for controlling weeds hence increasing yields, improving quality and reducing labor in crop production (Sill, 1982). According to Arevalo *et al*. (1992) and Cook *et al*. (1993), weed control in faba bean was achieved by application of a number of herbicides (Burnside *et al*., 1998; Marouf, Mustafa, and Mahi, 2004; Daba and Sharma, 2018).

Plant density is the number of plants per square meter, which in turn determines the area available to each plant and the degree of competition for limited resources in the field especially, for light, water and nutrients. This determines the yield and productivity of a particular crop (Dobocha *et al*., 2019). Optimum plant density of a crop variety at one location may not apply at other locations because of variation in soil type, growth habit, associated management factors and other environmental conditions (Dobocha *et al*., 2019; Hailu *et al*., 2019).

The effects of weed management practices vary with crop varieties, weed species, soil types, climatic conditions, previous cropping practices and the interest of the producer (Mengesha *et al.,* 2015). Moreover, growth and development of weeds can be suppressed by plant spacing, planting pattern, weeding techniques and frequencies (Mengesha *et al.,* 2015). Closely spaced crop provides good smothering potential on growth and development of weeds due to less availability of space and well distribution of seedlings per unit area, allow for the plants for nutrients and moisture uptake better than the weeds. However, no information is available in north shewa zone, on the effects of plant spacing and weeding management options on the production and productivity of faba bean. Few recommendations are available in such areas in Ethiopia and farmers are not aware of such practices due to absence of adequate research recommendations. Hence, the objectives of this study were: -

- To evaluate plant spacing and herbicides application on weed infestation level on faba bean.
- To evaluate the effect of plant spacing and herbicides application on yield and yield components of faba bean.

2. LITERATURE REVIEW

2.1. Orgin, Distribution and Production of Faba Bean

Faba bean is assigned to the Central Asian, Mediterranean, and South American centers of Diversity and believed to be a native to North Africa and southwest Asia, and extensively cultivated elsewhere (Harllan, 1969; Zohary and Hopf, 2000). Cubero (1974) postulated a near Eastern center of origin, to Europe along the North African coast to Spain, along the Nile to Ethiopia, and from Mesopotamia to India (Hawtin and Hebblethpiait, 1983). Secondary centers of diversity are ssumeed in Afghanistan and Ethiopia. However, Hajjar and Hodgkin (2007) reported the origin to be Central Asia. The Chinese used them for food almost 5,000 years ago, and they were cultivated by the Egyptians 3,000 years ago, by the Hebrews in biblical times, and a little later by the Greeks and Romans (Mihailovic *et al*., 2005; Singh and Bhatt, 2012). Probably, it was introduced by Europeans as a garden crop into India during the Sultanic period (1206–1555), during which its cultivation has been mentioned (Singh *et al*., 2013).

Faba bean is a much valued food legume in the Middle-East, the Mediterranean region, China and Ethiopia (Muehlbauer *et al.*, 1997; EIAR, 2018). In Ethiopia (probably one of the primary centers of diversification for faba bean), it is most likely introduced from Middle East soon after domestication through Egypt around the 5thmillennium B.C (Westphal, 1974). It is now widespread in Europe, North Africa, Central Asia, China, South America, the USA, Canada and Australia (Marouf, *et al.*, 2004 and EIAR, 2018).

The five top producing countries are China, Ethiopia, and Australia, France and United Kingdom and account for more than 75% of world production. China alone produced 34% of all faba beans in 2013 as indicated in FAO (2014). It has been also produced in Algeria, Morocco, Tunisia, Egypt, Sudan, Iraq, Afganistan, India, France, Italy, Mexico, Brazil and Argentina. However, faba bean utilization and production has been declining in the last decades by 50% between 1960-2010 due to the replacement of traditional cropping systems by industrialized cereal-based systems (Jensen *et al*., 2010; EIAR, 2018; Hailu *et al*., 2019). The Mean annual global production (tons) of Faba beans from 2008 to 2017 was 4,468,240.1 as reported by FAO (2019) and adapted from Erana Kebede (2020). The major producing regions in Ethiopia are: Tigray, Gojam, Gondar, Wollega, Wollo, Gamo Gofa, and Shewa. In addition, it is grown in the pockets in the rest of the country's highland and mid-highland regions with altitudes ranging from 1800 to 3000 m above sea level. Currently, the total area under cultivation is estimated to be 538,458 ha of land from which 89, 076.32kg are produced (Hailu *et al*., 2019).According to CSA (2018) report and as adapted from Erana Kebede (2020), faba beans covered 3.5% of the grain crop area (about 437,106.04 hectares) and its production was 3% of the grain production (about 92, 17615.35 kg).

2.2. Botany of the Crop

Faba bean is an annual herbaceous plant with coarse hollow stems and has a thick taproot up to one meter with abundant lateral roots (Duke, 1981).It has pinnate leaves, consisting of two to six leaflets. It is mainly pollinate by bumble bees. White flowers with purple markings form in clusters of one to five, and one to four pods usually developed from each flower cluster. Its height can reach up to two meters, it can develop pods up to 30 cm in height length and each pod contains three to twelve seeds. The crop requires moderate amount of water. Depending on the growing and environmental conditions, the pod takes about four to five months to mature get harvested (Hailu *et al*., 2019).

2.3. Ecological Requirement of Faba Bean

Faba bean is widely produced in areas with altitudes varying from 1800 to 3000 masl and within agro ecological zones ranging in between *Dega* and *Woinadega* of the country. In low land areas where an altitude is below 1800masl, it can be affected by drought and disease, however, chilling injury and disease may affect the crop if the altitude is above 3000 masl which may reduce the crop yield potential (Hailu *et al*., 2019). It needs 700mm to 900mm annual rainfall at *woinadega* and 800 to1100 mm at *dega* which is optimum conducive rainfall. In areas where there is shortage of rainfall, through irrigation it can give higher yield (EIAR, 2018).

Faba bean can tolerate a wide range of soil types and pH but grow best in loamy soils. It can grow on clay, silt or heavy deep, fertile and well-drained soils with adequate reserve of organic matter and a pH range of 6.0 -7.0. Sandy loam; sandy clay loam or clay loam with a clay content of between 15 and 35% is suitable. It will not grow well in soils that are compacted, too alkaline or poorly drained (EIAR, 2018; Hailu *et al*., 2019).

Faba bean require a cool season and for best growth, it is usually planted as a winter annual in subtropical or warm temperate regions. The temperature requirements are 10^0C with the minimum and the maximum is 27^0C. The maximum temperature during flowering should not exceed 30^0C. High temperatures during the flowering stage lead to abscission of flowers and a low pod set, resulting in yield loss. Day temperatures below 15^0C will delay maturity and cause empty mature pods. Soil temperature starting from germination to maturity stage should be ranged between 20-25^0C and also at between 10-15^0C may also be conducive (EIAR, 2018; Hailu *et al*., 2019).

2.4. Economic Importance of Faba Bean

Faba bean (*Vicia faba*, *L*.) is considered as one of the most vital seed legumes in terms of area, total production and consumption. Its green and dry seeds are consumed in human nutrition due to its high content of protein (28%), carbohydrates (58%), and many other vitamins. It can be used to make good quality silage and its straw is valued and considered a cash crop in Ethiopia, Egypt and Sudan (Muehlbauer *et al*., 1997; EIAR, 2018).

Besides it plays a good role in improving soil properties and fertility by adding about 20-30% nitrogen after harvest for benefit of the next crop (Abido and Tagour, 2017). Due to its atmospheric nitrogen fixing capacity and its ability to form endo symbiotic association with root nodulating bacteria (rhizobia) group called *Rhizobium leguminosarum* bv. V*icia*, it is used for green manure production or as crop rotation with the nationally important cereal crops like wheat, *teff*, barley and maize (Hailu *et al*., 2019).

2.5. Economic Importance of Weeds

Although some weeds have some beneficial impacts to man, his environment and livestock, weeds are problematic both in agricultural and non-agricultural areas so that they potentially cause economic losses. Weeds are responsible for significant crop yield losses and financial losses in agricultural production in the order of 10% per year worldwide (Ekwealor *et al*., 2019). They interfere in crops dates back to the beginning of agriculture, and they have been able to persist, in spite of long term control operations. They compete with other plants for limited resources (mainly nutrients, water and light), and competition can be successful through the use of certain strategies. Chief among these strategies is allelopathy, where secondary compounds inhibit germination and growth of other plants, and, as a chemical defense against herbivory. Weeds can affect animals by providing an inadequate diet or a diet that is unpalatable because of chemical compounds in the weed. They can directly reduce the quality of animal products by affecting milk production and fleece or hide quality. Reproduction performance is affected by toxins that cause abortion or killing of animals. Poisonous plants may contain one or more of hundreds of toxins from nearly major chemical groups, including alkaloids, glycosides, saponins, resinoids, oxalates, and nitrates (Halford *et al.*, 2001; Kavaliauskaite and Bobinas, 2006 ; Ekwealor *et al*., 2019).

Despite the negative impacts of weeds both in agricultural and non-agricultural areas, their beneficial impacts on man, his environments and animals cannot be overemphasized. Some beneficial weeds repel insects and other pests through their smell. The recent surge of public interest in medicinal ethno botany stems perhaps from the exotic association of medicinal weed plants with primary tropical rainforests. They are an important source of medicines for indigenous people and have a highly significant over-representation in indigenous pharmacopoeias about other plants. Sometimes weeds can serve as food because of their nutritional contents. Most of them are palatable and of acceptable quality for animal feed if they are grazed or cut when young. Wild oat patches are particularly good green forage, while other grassy weeds, such as quack grass, are also of high quality, generally similar to tame grasses. Weedy cereal crops can be cut when green, providing good livestock feed and reducing weed seed return in those areas (Ekwealor *et al*., 2019).

2.6. Losses in Different Crops due to Weeds

Weeds are one of the major constraints to crop cultivation that can affect crop yield based on their species composition and density (Kropff *et al*., 1992). They compete with cultivated food crops for limited resources such as water, nutrients, and light. This competition reduces yield and consequently farm income (Hassannejad and Porheidar-Ghafarbi, 2012). Infestation of weeds also encourage disease problems, serve as alternate host for deleterious insects and diseases, slow down harvesting, restricting operations, increase the cost of production, reduce the market value of crops and increase the risk of fire in perennial crops, plantation and forest reserves (Tena *et al*., 2012; Palumbo, 2013; Assefa Sintayehu, 2019). Currently, they are playing a significant role in making pest problems very complex.

One of the main constraints faced by farmers in the production of arable crops is effective weed control (Vissoh *et al*., 2004; Assefa Sintayehu, 2019).

Although most farmers are less concerned about the negative impact that weeds impose on their crop, study results indicate that weeds share up to 45% of the total annual losses of agricultural products (Upadhyay *et al*., 2011; Assefa Sintayehu, 2019). On average it has been estimated that they cause yield losses of about 10% in the less developed countries and 25% in the least developed countries (Akobundu, 1987). Yield losses due to weed competition in Africa range between 55 and 90% for maize, 50% for common bean, 40 and 80% for sorghum, 40 and 60% for cowpea, 50 and 100% for rice, 80% for cotton, 50 and 80% for wheat and groundnut, and 90% for cassava (Akobundu, 1987; Chikoye *et al*., 2004). EIAR (1988) reported that, the yield reduction in crop was: Maize 40%, Sorghum 30%, Wheat 35%, Barley 18%, *Teff* 30%, Lentils 50%, Chickpeas 30%, Faba beans 20%, Haricot beans 36%, Field peas 15%, and Soya beans 50%, Cotton 73%, Peppers 30%, and Coffee 62%. Uncontrolled weed populations can substantially reduce the yield of common bean up to 90% (Mengesha kebede *et al*., 2013; Mengesha kebede *et al*., 2015).

2.7. Losses and Damage caused by Weeds in Legumes

Weeds compete vigorously with legumes for water, nutrients and light due to the low competitive ability of legume crops during the early stages of their growth. In a variety of weeds infested dry beans (*Phaseolus vulgaris* L.); yield reduced by 10-80% (Parker and Fryer 1975), 60 to 66% (Arnold *et al*., 1993) and 33 to 51% (Idris 2001). The impact accounted for 70 % for white bean yields reduction (Malik *et al*., 1993).

Weeds caused considerable loss in yield of chickpea, although weeding by hand prevent weed competition during the period before the development of a full canopy cover has invariably been most effective, but limitations of labor and high labor costs often prevent the adoption of this method (Bahn and Kukula, 1987). Competition reduced seed yield of chickpea by 80% (Mohamed *et al*., 2004) and delayed weeding accounted for up to 80% loss in lentil grain yield (Mohamed and Nourai, 1994).

Uncontrolled growth of weeds reduced faba bean seed yield by 54% (Mohamed *et al*., 1994) Unrestricted weed growth reduced its grain and straw yield by 64% and 70%, respectively (Babiker and Khalid, 1990; Mohamed *et al*., 1992).

2.8. The Critical Period of Weed Control in Faba Bean

Critical periods for weed control are defined as the period in the crop growth cycle or the number of weeks after crop emergence. Weeds must be controlled during these periods to prevent un-acceptable yield losses that accounted for greater than 5% (Hall *et al.*, 1992; Knezevic *et al.*, 1994; 2002; Kavurmaci*et al.*, 2010). In order to provide more precise information for growers, critical periods for weed control should be determined specifically for a particular region by considering the weed composition and climatic conditions (Rajcan and Swanton, 2001; Kavurmaci*et al.*, 2010).

Faba bean do not compete well with weeds, particularly at their early stages. Also weeding faba bean late in the season critically affects its yields due to mechanical damage. Weeding at appropriate time or at critical period of competition is very crucial. In the rift valley areas, weeding at least once during early growing season (15 days after emergence) is reported to give reasonable yield compared to weeding twice at early (10 - 15 days) and mid-season (30 - 35 days). But, it should be noted that it is not advisable to weed the bean crop during and after flowering to avoid abortion, disease incidence and mechanical damage (EIAR, 2018).

Four weeks from sowing is the most critical period, in determining weed competition in faba bean (Dawood, 1989; Abido and Tagour, 2017).The critical period of weed competition in this crop occur from the 3rd to the 5th week after 50% crop emergence and if weeds are not controlled, seed yield can be reduced by 46% (Glasgow *et al*., 1976). Weeding once at two weeks after sowing gave similar yield to that of the weedy check, however, weeding once at one month after sowing relatively increased faba bean yield (Badawi, 1983). The fourth week after sowing is the most critical stage in crop weed competition, so weeding during this stage gave high yield as continuous weeding. Whereas, a single early weeding (2 weeks) or later than six weeks after sowing have no effect on the crop yield (Dawood, 1989; El Mahi, 2004).

2.9. Management of Weeds

Weeds are a challenging problem to pulse crop producers. Since the herbicides for most pulse crops are not locally available or very limited access, most small scale farmers could not access to use the chemical for weed control. Due to such reasons, hand weeding is the common cultural practice to remove weed from pulse crop fields. However, most of the farmers, where faba bean is widely grown, have been practicing differently at different growth stages of the crop in order to remove the weeds. Some of the farmers remove at the recommended time while others react after severe competition occurred. In the meantime, in addition to hand weeding, most farmers started hoeing to reduce weed pressure, on the other hand, where a shortage of animal feed is the main challenge, some farmers do not remove the weed until pod setting because they use it for animal feed. These temporal variations of weed managements considerably varied the yield performances of the crop and as a result its production and productivity across locations and seasons in which the average yield under small holder farmers' is not more than 1.8t ha^{-1} as compared to the crop's potential productivity (3.8t ha^{-1}) (Kissi Wakweya and Reta Dargie, 2017).

2.9.1. Preventive weed control

Preventing the introduction of new weed species is highly desirable and less costly than controlling them after they are established (Radosevich *et al*., 1997). Measures that should be taken to prevent introduction of new weed species include a national quarantine system, use of weed free crop seeds, avoidance of bringing in nursery soils containing weed seeds or vegetative parts, cleaning farm equipment, avoidance of bringing manure, mulches etc. from other farms, keeping irrigation canals free of weeds, controlling movement of livestock between fields and preventing weeds from setting seed (Akobundu, 1987).

2.9.2. Cultural weed control

Cultural weed management includes practices that favor crops in preference to weeds. These practices include hand weeding, mechanical weeding, burning, flooding, mulching and crop rotation (Ennis, 1977).

Hand weeding is probably the oldest method of weed control and is consisted of hand pulling; slashing, hoeing and mowing of weeds (Akobundu, 1987).This may be the only practical method available to small farmers. Other than requiring labor, it usually requires no further cash outlay. This is an advantage in situations where cash is not readily available but where labor is from the farmer's immediate family or through non-cash exchange. It may be the only method that can be used to weed broadcast-seeded crops where herbicides are not available (FAO, 1989).

Hand weeding is intensive and slow compared to other methods. It may damage crop roots. It is usually delayed until the weeds are easily seen and can be grasped. Yield losses can occur before weeds are removed. Because hand weeding is intensive, farmers may wait until the weeds are quite large so as to do only one weeding; whereas two weeding when the weeds are small is better in terms of reducing yield losses. In rainy weather, hand weeding may be difficult and possibly damage the crop. Besides, if weeds are simply piled up after pulling, some species may re-root and grow again. Some weeds are not easily removed by hand weeding. Handheld tools will make weeding faster and easier compared to hand pulling, but have the same general advantages and disadvantages (FAO, 1989).

Mechanical weeding includes all weed control practices where a mechanical device is used for weed control with animals or fossil fuel as the source of energy. Good weed control can be achieved by a rigid harrow before and after weed emergence. Weeds are sensitive to harrowing only at cotyledonous to the rosette stage because a harrow has a burial effect. Farmers usually carry out two distinct types of tillage for weed control purposes; these are delayed tillage and blind tillage (Ennis, 1977). Delayed tillage involves preparing the seedbed and waiting until weeds emerge before lightly cultivating the soil again and planting the crop seeds. Light tillage is when crop seeds are planted after the usual land preparation and lightly cultivated after weeds but before crop emergence (Akobundu, 1987; Radosevnich *et al*., 1997).

Burning weeding has been used to control weeds. This method is used to get rid of undesirable crop residues which may harbor diseases as well as weed seeds. It is also used on pasture areas to encourage more palatable species. It is generally not useful in most Ethiopian conditions (FAO, 1989). Most burning is done before crops are planted. It often destroys many broad leaf weeds, but it can lead to the predominance of perennial species (Anon, 1986). Uncontrolled burning is deleterious to the environment; it can cause soil erosion on slopes, destruction to property and life (Akobundu, 1987; El Mahi, 2004).

Crop rotation plays a long term role in weed control by preventing particular weed species from adapting themselves to the growth cycle of a specific crop (Akobundu, 1987). By changing from one crop to another, the different growth habits and associated agronomic practices will help to change the environmental and management conditions encountered by the weeds. This represents a change of strategy which will help to avoid selective pressures which may favor one species over another (Akobundu, 1987).

2.9.3. Biological control

This method uses a biological agent other than man to control weeds. Multiple host agents are those that can control a variety of weed species and are largely nonspecific. Examples are goats, sheep, geese, and fish. These agents can be manipulated directly by man, are best used in non-crop situations, and will show selectivity by preferring certain species (FAO, 1989). Specific host agents are insect or disease organisms that affect a single host species (Zenebech Bizualew, 2018).

The influence of insects, mites, plant pathogens and other organisms on plant growth is a natural process and has existed since the origin of plants (Anon, 1986). Biological weed control may be the most effective and environmentally friendly approach against invading plant species threatening and endangering ecosystems and wild species (Holden *et al*., 1992; Anon, 1994, Gupta, 2004;Zenebech Bizualew, 2018).

2.9.4. Chemical control of weeds

Herbicides are chemical compounds used to kill or inhibit growth of undesirable plants (Quantick, 1985). A successful herbicide should be safe to the crop with reliable performance and must not be influenced by soil or any environmental factors (Khair *et al.*, 1980). Moreover, herbicides should have safety records to environment and users alike (Khair, 1981). They act on weeds by contact or systemic action. They may be residual or non-residual. Time of application could be pre planting, pre-emergence or post-emergence. They could be used alone or in mixture. Herbicides could be classified as grass or broad-leaf weed killers. However, some of them are effective on both (Ashton and Grafts 1973). The use of post-emergence herbicides allows the growers to design effective control strategies against a particular weed spectrum in a given field (Hager and Renner, 1994).

2.9.5. Integrated weed management

Integration of weed control methods is an effective and workable practice that is ecologically and economically viable to the farmers. Herbicides constitute a highly efficient technique for controlling weeds hence increasing yields, improving quality and reducing labor in crop production (Sill, 1982). According to Arevalo *et a*l. (1992; Cook *et al*., (1993), satisfactory weed control was achieved in faba bean by application of herbicides. However, commodity prices, herbicide resistance, environmental and human health hazards associated with herbicides, difficulty in use of mechanical weeding in heavy soil as well as receiving heavy rains limitations to effective weed management have forced faba bean growers to implement integrated weed management (IWM) practices. These include a combination of cultural, mechanical, and chemical weed management techniques (Burnside *et al*., 1998; Nano Alemu Dab and JJ Sharma, 2017).Integration of weed control methods implies that some short or long-term strategy is being systematically employed to reduce weed infestations. It involves a degree of foresight and predictability in order to plan treatments and integrate them in to the cropping system (Zenebech Bizualew, 2018). As cited in Zenebech Bizualew, (2018), the integrated use of herbicides with hand weeding might have helped in producing more vigorous leaves under low weed infestation that improved the photosynthetic efficiency of the faba bean (*Vicia faba* L.) and supported a large number of pods (Abdel LY, 2008). More pods might be produced with integrated use of herbicides with hand weeding in soybean than herbicides application alone (Amoabeng, *et al*., 2014). The use of fluchloralin and pendimethalin at lower rates (1.0 kg ha^{-1} each) in combination with hand weeding resulted in higher number of pods $plant^{-1}$ which was at par with weed-free in soybean (Peer, *et al*.**,** 2013; Zenebech Bizualew, 2018).

2.9.6. Plant Spacing

Growth and development of weeds can be suppressed by plant spacing. Closely spaced crop provides good smothering potential on growth and development of weeds due to less availability of space for growth and development, and also well distribution of seedlings per unit area, thereby competing for nutrients and moisture better than the weeds do. A crop's ability to suppress weeds can be enhanced if it is able to acquiring limiting resources earlier in the growing season or sequestering them in the form of more crop plants per unit area (Page and Willenborg, 2013). Plant spacing significantly influence the incidence of an infestation by weeds and the performance of crop plants due to their competition for limited natural resources (Mengesha *et al*., 2015; Dobocha, *et al*., 2019).

Exploiting all avenues to increase crop production under any condition to meet the demands of the teeming population would not be out of order, thus the need for a good choice of spacing. Reports of inconsistent yield effects of plant spacing uniformity could be the consequence of plant density difference and the method through which plant spacing variability was measured (Fowler 2012; Thompson, 2013). Yield increases are dependent on many factors ranging from water availability and distribution, nutrient supply as well as spacing which is a major determinant of yield addition or subtraction (TLC, 2009). Increasing population density remains the most effective way to increase whole-plant yield in short-season. Narrow row spacing was found not to have a negative effect on whole-plant yield (Baron *et al*., 2006; Boloyi, 2014). Wider spacing encourages growth of weed and thus more labor and increase in cost of production. Sharifi *et al.* (2009) concluded that plant population density influenced maize dry matter yield. Moderate densities were seen as good, and significant reduction occurred only at very high densities. Closely spaced crop provided good smothering potential on weed growth and development due to less availability of space for growth and development, and also well distribution of seedlings per unit area. Thus, weeds can be controlled by using appropriate planting pattern and frequency of weeding (Ukonze *et al*., 2016, Mekonnen *et al.*, 2017).

Plant density is another important factor determines growth, development and yield of faba bean(McRae *et al*., 2008; Hassan and Khaliq, 2008; McMurray, 2004; Mathews *et al*., 2008). However, maintenance of optimum planting density is always a big problem to the farmers. Substandard plant density result in high weeds infestation, poor radiation use efficiency and low yield, while dense plant population on the other hand cause lodging, poor light penetration in the canopy, reduce photosynthetic production due to shading of lower leaves and drastically reduce the yield (Vassilev, 1998; Jettner *et al*., 1998 a &b; Lemerle *et al*., 2004; Lemerle *et al*., 2006;). Seed yield was highest at larger plant population ha^{-1} compared with less plants ha^{-1} (Salih, 1992). The thicker density of plants ha^{-1} produced higher seed yields than thin density Rajender *et al*., (1993). The optimum plant density was 200,000 to 240,000 plants ha^{-1} (Mathews *et al*., 2008), while Armstrong *et al*., (2008) reported increase in yield up to 800,000 plants ha-1(Shad K. Khalil *et al*., 2011).

3. MATERIALS AND METHODS

3.1. Description of the study area

The experiment was carried out under main cropping season at Debre Berhan University farm station, which is situated at 130 km from Addis Ababa on the main highway to Dessie and Mekele. The field has latitude and longitude of 9°41′N and 39°32′E respectively and with an altitude of 2,840 meters above sea level. The average annual rainfall is 965.25 mm with an average maximum temperature of 20.1^{o}C and average minimum temperature of 6.5^{o}C with the coldest season occurring between October and January. The soil type of the study area according to the harmonized FAO soil viewer model, it has fine clay (light) top and subsoil texture according to USDA classification with Vertic nature having bulk density (kg/dm^3) ranging between 1.4 - 1.58 and organic carbon (% by weight) from 0.41 to 0.56(Harmonized World Soil Database Viewer Model Version 1.2, FAO).

3.2. Experimental Materials

Faba bean (*Vicia faba* L.) variety (locally called *wolki*) which was released in 2008 from Holleta Agricultural Research Center, Ethiopian Agricultural Research Institute (EIAR), (EIAR, 2018) (Table 1) and two registered herbicides in Ethiopia and commonly used by farmers were gallant super and fusillade were used. The herbicides were applied as per the recommendation rate of the manufacturers at the rate of liter/ha using manual knapsack sprayer of 15 liter capacity.

Table 1. Description of faba bean variety used for the experiment

Name of Variety	**Year of release**	**Days to maturity**	**Suitable agro-ecology**		**1000 seed weight (gm)**	**Flower Color**	**Seed color**	**Yield (q/ha)**	
			Altitiude (m.a.s.l.)	Annual rainfall (mm)				On station	On farm
Wolki	2008	133-146	1900-2800	700-1000	676	White by black	Light green	24-52	20-41

3.3. Treatments and Experimental Design

The experimental design used was randomized complete block and replicated three times. The treatment comprised3 plant spacing (35 x 15 cm; 40 x 10 cm and 45 x 5 cm inter- and intra-row spacing) and four weed management options: gallant super herbicide spray, fusillade herbicide spray, hand weeding and weedy check as control. The size of each plot was 2.00 m length x 2.10m width (Table 2).

Table 2. Treatments and their combinations

Treatments		Treatments' Combinations
Spacing	**Weed management**	
35 cm × 15 cm	Gallant super	35 cm × 15 cm + gallant super
	Fusillade	35 cm × 15 cm + fusillade
	Hand weeding	35 cm × 15 cm + hand weeding
	Weedy check	35 cm × 15 cm + weedy check
40 cm × 10 cm	Gallant super	40 cm × 10 cm + gallant super
	Fusillade	40 cm × 10 cm + fusillade
	Hand weeding	40 cm × 10 cm + hand weeding
	Weedy check	40 cm × 10 cm + weedy check
45 cm × 5 cm	Gallant super	45 cm × 5 cm + gallant super
	Fusillade	45 cm × 5 cm + fusillade
	Hand weeding	45 cm × 5 cm + hand weeding
	Weedy check	45cm × 5 cm + weedy check

3.4. Experimental Procedures

The land was ploughed to 30 cm depths using tractor, harrowed and leveled. Broad beds were prepared using hand tools manually. Seeds were sown on 2.10 m × 2.0 m (4.20 m^2) plots size with 6, 5 and 4 rows of plants in 35, 40 and 45 cm inter row spacing. Spacing between plots was 50cm and 1m wide between blocks. The outer rows from each side in all the plots were considered as border rows. Thus, all plants' phenological parameters, growth, yield and yield related data were collected only from the remaining rows.

Di ammonium phosphate (DAP) was drilled in rows at the rate of 100 kg ha^{-1} at sowing as per recommendation for faba bean (Mandefro *et al.*, 2009; EIAR, 2018) uniformly for all plots. Hand weeding treatment was applied twice, the first at 3 and the second at 6 weeks after emergence. Herbicides gallant super and fusillade were applied at rate of 1 and 1.5 lit ha^{-1} at three weeks emergence using knapsack sprayer 15 liter capacity. For the weedy check treatment the plots were left unweeded to use as control.

3.5. Data Collected

3.5.1. Weed infestation

Weed density m^{-2} was determined twice, the first at three weeks after crop emergence and the second at 15 days before harvest. The quadrate (0.25m^2 size) was laid down at two points in each plot. The weed flora within the experimental plots was recorded by throwing a quadrant (0.5 m × 0.5 m) randomly at two spots in twice replications. The species were categorized into their botanical families with the aid of flora books (Stroud and Parker, 1989; Melaku, 2008) and expertise. In addition, other weed parameters were also determined. These were as follows:

Frequency of weed: it is the percentage of quadrates in which a particular weed species occurred. It was calculated as:

$$Frequency = \frac{Total\ number\ of\ quadrats\ in\ which\ the\ weed\ species\ occur}{Total\ number\ of\ quadrats\ studied}\ x\ 100$$

Abundance of weed: is the population density of a weed species expressed as the number of individuals per unit area. It was determined as:

A = (∑w)/N

Where: A = abundance

∑w = sum of individuals of a particular weed species in all quadrats

N = total number of quadrats

Dominance of weed: Abundance of an individual weed species in relation to total weed abundance

D = A * 100/(∑W)

Where: D = dominance of a particular species

A = Abundance of the same species

∑W = total abundance of all weed species

$$Densit = \frac{Total\ numer\ of\ individuals\ of\ a\ species\ in\ all\ quadrants}{Total\ numer\ quadrants\ studied}$$

$$Relative\ frequency = \frac{Frequency\ of\ individual\ of\ species}{Total\ frequency\ of\ all\ species} x100$$

$$Relative\ Densit = \frac{Density\ of\ individual\ of\ species}{Total\ density\ of\ all\ species} x100$$

$$Relative\ abundance = \frac{Abundance\ of\ individuals\ of\ species}{Total\ abundance\ of\ all\ species} x100$$

According to Rana SS and MC Rana. 2016. Principles and Practices of Weed Management. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 138 pages.

3.5.2. Phenological parameters

Days to 50% emergence: Days to 50% emergence was recorded as the number of days from sowing to when 50% of the plants emerged in each plot.

Days to 50% flowering: Number of days 50% flowering was recorded as the number of days from sowing to the time when 50% of the 10 pre-tagged plants showed first flower.

Days to 90% physiological maturity: It was recorded in each plot, as the number of days from sowing to when 90% of the 10 pre-tagged plants senesced and the leaves and pods turned yellow in color.

3.5.3. Growth parameters

Stand count after thinning: The initial plant stand count was recorded by counting the total number of plants per net plot area immediately after thinning at establishment.

Stand count at harvest: final plant stand count was taken from net plot areas when the plants attained harvest maturity and converted to hectare basis.

Total leaf area (cm^2): It was determined by measuring the area of leaves at three positions along plant height from top, middle and lower part of randomly selected plants from each plot using square papers and averaged.

Leaf area index (LAI): It was calculated as the ratio of total leaf area to the respective ground area occupied by the plant for each plot.

Plant height (cm): It was recorded from 10 randomly selected plants per net plot area by measuring the height from the ground level to the apex at the time of physiological maturity and averaged.

Number of tillers per plant: This was determined by counting of primary branches on the main stem from 10 randomly selected plants from the net plot area.

3.5.4. Yield and yield components

Number of pods per plant: It was counted from 10 randomly taken plants at harvest and expressed as the average number of pods per plant

Number of seeds per pod: It was determined by dividing the total number of seeds from ten randomly selected plants to the total number of pods of the selected plants.

Hundred seed weight (g): It was determined by taking the weight of 100 randomly sampled seeds from the total harvest from each net plot area and adjusted to 10% moisture level.

Aboveground dry biomass (kg/ha): The aboveground dry biomass weight was determined at physiological maturity by cutting at ground level, 10 randomly sampled plants and sun drying the biomass. The sun-dried aboveground biomass was weighed and multiplied by the number of plants in the net plot area and then converted into kg ha^{-1}.

Grain yield (kg/ha): Grain yield was determined after threshing the seeds harvested from the net plots. The weight then adjusted to 10.5% moisture content and converted to kg/ha.

Harvest index (HI): It was calculated as the ratio of grain yield to total above-ground dry biomass yield multiplied by hundred.

3.6. Data Analysis

The data were statistically analyzed using SAS version 9.1 computer software. Analysis of variance (ANOVA) was used to evaluate treatments and their interaction effects. The significance differences among treatment means was tested using the least significant difference (LSD) test at $p \leq 0.05$ probability levels.

3.7. Cost - Benefit Analysis

The partial budget analysis was conducted to determine the economic feasibility of weed management practice as described by CIMMYT (1988). The faba bean seed was purchased from the local market and the total price of the yield obtained from each treatment was computed on hectare basis. Input costs like herbicide and labor were converted into hectare on the basis according to their frequencies usage. The price for faba bean seed per kg was assessed according to local market. Herbicides cost was estimated based on the price of market. Cost of the labor was estimated in Birr per man-days; cost of spray and spray equipment to spray one time per hectare were calculated. Cost of spray equipment (knapsack sprayer) was in Birr per day. Based on the obtained data from the above mentioned parameters, cost benefit analysis was performed by using partial budget analysis. Marginal analysis is concerned with the process of making choice between alternative factor-product combinations considering small changes. Marginal rate of return is criteria which measures the effect of additional capital invested on net returns using new managements compared with the previous one (CIMMYT,1988). It provides the value of benefit obtained per the amount of additional cost incurred. The formula is as follows:

$$MRR = \frac{DNI}{DIC}$$

Where: MRR is marginal rate of returns; DNI is difference in the net income compared with control and DIC is the difference in the input cost compared with control.

4. RESULTS AND DISCUSSION

4.1. Weed Density and Floras

4.1.1. Weed density

Quadrates with size of 0.5 m x 0.5 m were thrown in each plot at two spots and the number of individual weed species per quadrates was counted and converted into per square meter. This sample was taken twice, at after three weeks of crop emergence and 15 days before harvest. The result showed that interaction effect of plant spacing and weed management practice significantly ($p \leq 0.05$) reduced weed density (Table 3).

Table 3. The interaction effect of weed control options and plant spacing on weed density (m^{-2})

Treatments	Weed density at 3 weeks after emergence			Weed density at 15 days before harvest			
	Grass M^{-2}	Leafy M^{-2}	Total M^{-2}	Grass M^{-2}	Leafy M^{-2}	Total M^{-2}	Reduction (%)
35 cm × 15 cm + gallant super	885.0	58.0	943.0	177.0	47.0	224.0	76.2
35 cm × 15 cm + fusillade	947.0	63.0	1010.0	142.0	44.0	186.0	81.6
35 cm × 15 cm + hand weeding	883.0	80.0	963.0	26.0	3.0	29.0	97.0
35 cm × 15 cm + weedy check	915.0	84.0	999.0	683.0	63.0	746.0	25.3
40 cm × 10 cm + gallant super	729.0	56.0	785.0	125.0	38.0	163.0	79.2
40 cm × 10 cm + fusillade	831.0	67.0	898.0	108.0	31.0	139.0	84.5
40 cm × 10 cm + hand weeding	716.0	63.0	779.0	19.0	2.0	21.0	97.3
40 cm × 10 cm + weedy check	859.0	67.0	926.0	601.0	46.0	647.0	30.1
45 cm × 5 cm + gallant super	811.0	56.0	867.0	129.0	35.0	164.0	81.1
45 cm × 5 cm + fusillade	781.0	51.0	832.0	93.0	32.0	125.0	85.0
45 cm × 5 cm + hand weeding	852.0	88.0	940.0	17.0	2.0	19.0	98.0
45cm × 5 cm + weedy check	903.0	46.0	949.0	558.0	39.0	597.0	37.1

The maximum reduction (98.0%) in total density of weeds was observed by the combination of 45 cm × 5 cm plant spacing with twice hand weeding followed by 40 cm × 10 cm with one hand weeding (97.3%) and 35 cm × 15 cm with twice hand weeding (97.0%). The minimum reduction in total weed density was observed in the combination of weedy check with 35 cm × 15 cm (25.3%), although it was non-significantly varied with those of weedy check + 40 cm × 10 cm (30.1%) and weedy check + 45 cm × 5 cm (37.1%). Increasing plant density per $m^2$from the 35 cm × 15 cm to the 45 cm × 5 cm plant spacing, there was a significant reduction in the total weeds density for the same weedy check. This might be due to the highest plant population density (the cases of 45cm × 5cm spacing) caused a reduction in weeds growth. Similar results were reported by Farghaly (2002), El-Hindi *et al.* (2008), Abd El-Rahman (2014); Mengesha *et al.* (2015), Kassahun Zewdie and Kiflom Yohannes (2019) who stated that reduction in weed growth due to quicker row closure, which decreased the light penetration to the weeds emerging below the crop canopy was observed in the cases of closer spacing. Similarly, Holmes and Sprague (2013) reported that weed suppression was maximized in narrower than wider spacing in common bean.

In the current study twice hand weeding was the most effective weed management for faba bean in reducing weed density followed by fusillade then gallant super herbicide spray with 45 cm × 5 cm plant spacing. This result might be due to growing more plants per plot resulted in earlier canopy closure, increased shading on weeds, increased crop competitiveness and reduced weed growth. In line with this result, various investigators found that twice weeding was the most effective weed control practice for reducing weed density and dry matter accumulation in faba bean plants (Kushwah and Vyas, 2005; El-Metwally and Abdelhamid, 2008 and El-Metwally, 2016). Mengesha *et al.* (2015) also reported that two weeding by hand-hoeing at two and five WAE reduced weed density by decreasing weed seed bank due to early weeding and later emerged weeds subsequently . Tilahun (1998) reported that common bean required at least two early weeding (15 and 30 days after emergence) for efficient weed management, which led to significantly higher crop yields.

4.1.2. Weed species composition, their frequency, abundance and dominance

The experimental field was found to be infested with different species of grasses and broad leaved weeds as presented in table below (Table 4).

Table 4. The major problematic weedspecies' composition, frequency, abundance and dominance

			Weed density at 3 WAE				Weed density at 15 DBH			
Scientific Names	Family Names	Amharic Names	Fr	De	Ab	Do	Fr	De	Ab	Do
Snowdenia polystachya	*Poaceae*	Muja	100	7779	0.7	71.4	100	2288	0.7	74.5
Avena fatua	*Poaceae*	Sinar	100	1444	0.1	13.3	100	446	0.1	14.5
Cyperuse sculentus	*Cyperaceae*	Engcha	100	841	0.1	7.7	100	170	0.1	5.5
Stellaria media	*Caryophyllaceae*	Tijasiga	100	736	0.1	6.8	100	131	0.001	4.3
Bidenspachyloma	*Asteraceae*	Adabeba	100	54	0.001	0.5	100	20	0.001	0.7
Galiumspurium	*Rubiaceae*	Ashikrt	100	41	0.001	0.4	100	16	0.001	0.5
Total				10895	1.0	100		3071	1.0	100

Where: WAE = week after emergence, DBH = days before harvest, Fr= frequency, De= density, Ab= abundance and Do= dominance

Six weed species were found in all the plots. The grass weeds were: *Snowdenia polystachya*, *Cyperuse sculentus* and *Avena fatua*, whilethe broad-leaved weeds were: *Stellaria media*, *Bidens pachyloma*, and *Galium spurium* (Table 4). Since all identified six weed species were found on the studied plots, the frequency was 100% during both counting (3 WAE and 15 DBH). The most abundant weed species was *Snowdenia polystachya* with value of 0.7 during both sampling periods. In addition, *Snowdenia polystachya was* the most dominant weed species (71.4% at 3 WAE and 74.5% at 15 DBH) followed by *Avena fatua* (13.3% at 3 WAE and 14.8% at 15 DBH). Whereas, *Bidens pachyloma and Galium spurium* were the least dominant weed species found in the experimental plots at both sampling periods.

4.2. Phenological Parameters

4.2.1. Days to flowering

Days to 50% flowering was significantly ($p < 0.05$) affected by plant spacing, weed management practices and their interaction (Table 5).

Table 5. The interaction effect of spacing and weed management practice on days to 50% flowering (DTF) for faba bean during the growing season

Spacing * weed management	**DTF**
45cm x 5cm* Weedy check	54.00 [a]
45cm x 5cm * Gallant super	53.67 [ab]
45cm x 5cm * Fusillade	53.67 [ab]
35cm x 15cm * Weedy check	53.33 [a-c]
40cm x10cm* Gallant super	53.33 [a-c]
40cm x 10cm *Weedy check	53.00 [a-c]
40cm x 10cm * Fusillade	52.67 [a-c]
40cm x 10cm * Hand weeding	52.67 [a-c]
35cm x 15cm * Hand weeding	52.33 [bc]
35cm x 15cm *Gallant super	52.33 [bc]
45cm x 5cm * Hand weeding	52.33 [bc]
35cm x 15cm * Fusillade	52.00 [c]
LSD (0.05)	0.829
CV (%)	0.9

Means of the same category followed by different letters are significantly different at 5% probability.

Plants grown with the combination of 35 cm × 15 cm inter and intra row spacing and fusillade herbicide application flowered early (52.00 days) as compared to the other treatments. However, there was no statically difference in between plots of 45 cm x 5 cm with hand weeding, 35 cm x 15 cm with gallant super and 35 cm x 15 cm with hand weeding in that their value was 52.33 days each. The maximum value (54 days) was recorded under plots having spacing of 45 cm x 5 cm and weedy check but statically similar with plots treated by 45 cm x 5 cm with gallant super and 45 cm x 5 cm with fusillade. This might be due to the fact that wider spacing and good management practices had better light interception as compared to the narrower spacing resulted in less number of days to flower as faba bean needs direct sunlight coverage for its various physiological processes. In addition, this might be more nutritional area available in wider intra- row spacing might have caused the crop to flower earlier than the closer spacing. Meanwhile, in narrower intra- row spacing due to competition for light, nutrients, moisture and space, the crop revealed delayed flowering as intra-row spacing decreased. In agreement with this result, Hailu *et al*. (2019) reported that days to flowering were significantly decreased in wider plant spacing and good management practice. Moreover, Farag and EI Shamma (2004) reported that the wider plant spacing reduced number of days to flowering in broad bean as compared to narrow plant spacing. Gebremariam *et al*. (2018) also reported that the shortest mean days to flowering row planted, fertilized and twice weeded. Mengesha *et al.* (2015) also indicated the days to flowering in weed-free plots were significantly earlier than the other treatment, which indicates the number of days to flowering was significantly delayed due to weed infestation throughout the crop growth over other treatments. The shading out of crop plants by the weeds might have reduced sunlight penetration, thereby prolonging the vegetative growth and resulting in delayed flowering of common bean. This might have reduced the vegetative growth and delayed the transition to the reproductive period (Mengesha *et al.*, 2015). In contrast, Turk *et al.* (2003*)* found that the denser plant population hastened days to flowering in lentil (Hailu *et al*., 2019).

4.2.2. Days to physiological maturity

The main effects of plant spacing and weed management practices significantly ($p < 0.05$) affected days to 90% physiological maturity:however, their interaction did not affected this parameter (Table 6). The days at which 90% of the population to reach maturity under twice hand weeding treated plots was earlier (124.9 days). The weedy check plots needed a maximum of 126.2 days to 90% to physiological maturity than the rest weed management practices. This indicated that the number of days to physiological maturity was delayed in weedy check treatment due to increased weed competition over other treatments.

Table 6. The main effects of plant spacing and weed management practices on days to 90% maturity of faba bean during growing season

Spacing	**DTM**
45cm x 5cm	126.3 [a]
40cm x10cm	125.8[b]
35cm x 15cm	124.5 [c]
LSD (0.05%)	0.476
Weeding	
Weedy check	126.2 [a]
Fusillade	125.8 [ab]
Gallant super	125.3 [bc]
Hand weeding	124.9 [c]
LSD (0.05%)	0.549

DTM = days to 90% to maturity. Means of the same category followed by different letters are significantly different at 5% probability.

In line with the current result, Magnesia *et al.* (2015) also indicated that days to 90% physiological maturity in two time hand-hoeing frequency were significantly earlier, indicates that the number of days to physiological maturity was significantly delayed due to weed infestation throughout the crop growth over other treatments. The shading out of crop plants by the weeds might have reduced sunlight penetration, thereby prolonging the vegetative growth and resulting in delayed flowering and physiological maturity of common bean. This might have reduced vegetative growth and it delayed the transition to reproductive period and finally to physiological maturity. In line with this result, Mitiku *et al*. (2012) reported that with increase in the dry weight of *Parthenium*, the duration required by the common bean plants to reach physiological maturity was prolonged.

Moreover, Plant spacing significantly affected the days to 90% physiological maturity and the plant spacing of 35 cm x 15 cm has recorded the earliest (124.5 days) days to 90% physiological maturity while the longest (126.3 days) day to this parameter was obtained from 40 cm x10 cm plant spacing (Table 6). . In line with this result, Lopez *et al.* (2005); Oad *et al.* (2002) and Almaz and Kindie, (2017) reported that with increase in the plant density, the duration required by the common bean plants to reach physiological maturity was prolonged. Hodgson and Blackman (2005) and Hailu *et al*. (2019) reported that narrower row spacing and plant spacing prolonged maturity days of faba bean compared to wider spaced crops. Similarly, Oad *et al.* (2002) reported that the closer row and plant spacing delayed maturity days of sunflower as compared to wider spacing.

4.3. Growth and Growth Related Parameters

4.3.1. Number of stands per plots

The number of stands counted just after thinning was significantly affected by plant spacing while the effect of weed management practices and its interactions with plant spacing did not affect this parameter (Table 7). The maximum number of stands 15 days before thinning was 148.7 and it was recorded on 45cm x 5cm plant spacing. The minimum number of stand (72.9) was recorded on plot with 35cm x15cm spacing. This value was 91.8 for plot having 40cm x10cm plant spacing. These differences was due to variation of inter and intra row spacing selected and/or plant population per plots designed for experimental test. These values were little lower due to germination problem than that actually to be per each plot just after thinning (i.e. 78, 100 and 160 plants per 35cm x 15 cm, 40 cm x10 cm and 45 cm x 5cm plant spacing's respectively).

Table 7. The main effect of plant spacing and weeding practices on growth parameters of faba bean during the growing season

	SBT		**SBH**
Spacing		**Spacing**	
45cm x 5cm	148.7 [a]	45cm x 5cm	189.2 [a]
40cm x10cm	91.8 [b]	40cm x10cm	141.0 [b]
35cm x15cm	72.9 [c]	35cm x15cm	119.6 [b]
LSD (%)	3.78	LSD (%)	22.77
Weed Management			
Weedy check	105.6 [a]	Hand weeding	234.0 [a]
Fusillade	104.3 [a]	Fusillade	134.0 [b]
Gallant super	104.0 [a]	Gallant super	121.0 [b]

Hand weeding	103.9 [a]	Weedy check	110.8 [b]
LSD (%)	4.37 [ns]	LSD (%)	26.29

SBT is stand count before thinning; SBH is stand count before harvest. Means of the same category followed by different letters are significantly different at 5% probability.

The main effects of plant spacing and weed management practices significantly affected the numbers of stands per plots 15 days before harvest. However, this parameter was not affected by the interaction effect of these treatments (Table 7). The maximum number of stands before harvest was 189.2 and recorded on 45cm x 5cm plant spacing. However, the minimum value was 119.6 on plots with 35cm × 15cmand it was 141.0 for 40cm x10cm plant spacing. The higher percentage increment (1.64%) in numbers of stands per plot on 15 days before harvest compared to the number of stands after thinning was observed on 35cm x15cm followed by 40 cm x10 cm (1.54%).It was 1.27% increment for 45cm × 5cm plant spacing. This might be because of the higher tillers per plant for widerintra row plant spacing (35cm x15cm). In agreement to this result, Maguje Masa*et al*. (2017) reported, closer inters and intra row spacing combination resulted in higher stand reduction than wider spacing combinations in Common bean (*Phaseolus vulgaris* L.). The reasons for this highest percent reduction of stand count at the narrowest inter and intra row spacing might be due to crowding effect. There is a possibility that at narrower inter and intra row spacing (with higher population density) smaller plants crowded out and die due to intense competition for growth resources. Njoka EM *et al.* (2005) also reported that increased plant mortality as density of plant increased in common bean. Similarly, Idris AL (2008) reported reduced plant competition and plant mortality at lower plant population on faba bean (Maguje Masa et *al*., 2017). Hailu *et al.* (2019) also concluded that the widest plant spacing gave significantly higher tiller number and the narrowest spacing gave lower number of primary tillers led to higher and lower number of stands per plot. This is due to the fact that, as space among plants increased ample resources become available for each plant that enhances the lateral vegetative growth of the crop.

With respect to weed management practices, the number of stands per plots 15 days before harvest was maximum (234.0) for plot treated with twice hand weeding (Table 7). The minimum valuewas110.8 and it was observed on weedy check plot. They were 134.0 and 121.0for fusillade and gallant super herbicide treatments. This might be due to the reduction in weed competition as result of weed management practice used that enhances the growth and development of primary tillers and thereby number of stands of faba bean at harvest.

4.3.2. Number of tillers per plots

The main effect of plant spacing, weed management practices and their interaction significantly affected the number of tillers per plant of faba bean at 5% probability (Table8).

Table 8. The interaction effects of plant spacing and weeding management practices on number of tiller per plant for faba bean during the growing season

Spacing	**Weeding**	**NTPP**
35cm x 15cm	Hand weeding	2.833 [a]
40cm x 10cm	Hand weeding	2.667 [a]
45cm x 5cm	Hand weeding	1.733 [b]
35cm x 15cm	Fusillade	1.467 [bc]
40cm x 10cm	Fusillade	1.300 [bc]
35cm x 15cm	Gallant super	1.250 [bc]
45cm x 5cm	Fusillade	1.183 [bc]
40cm x 10cm	Gallant super	1.167 [bc]
45cm x 5cm	Gallantsuper	1.117 [bc]
35cm x 15cm	Weedy check	1.033 [c]
40cm x 10cm	Weedy check	1.017 [c]
45cm x 5cm	Weedy check	1.013 [c]
LSD (%)		0.389
CV (%)		15.9

NTPP is number of tillers per plant. Means of the same category followed by different letters are significantly different at 5% probability.

Twice hand weeded plots with 35 cm x15 cm plant spacing had maximum tiller capacity (2.833) followed by 40cm x 10cm and with the same weeding management option (2.67) though they were not statically different. Plots having 45cm x5cm plant spacing and left as weedy check had the minimum value (NTPP = 1.013). This value was statically similar with 40cm x 10cm and weedy check (NTPP =

1.017) and 35cm x 15cm and weedy check (NTPP = 1.033) combinations. Moreover, the use of either of the three plant spacing's combined with either of the two herbicides (fusillade and gallant super) was not statically different one from other. From the result, the wider the plant spacing per plots integrated with twice hand weeding management option showed higher tillers number than the narrower plant spacing plots and weedy checks. In addition, using herbicides on any one of the plant spacing was the next superior compared to weedy checks but varied plant spacing. This might be due to reduction in competition for resources needed for growth and development because of weed managements. Hailu *et al*. (2019) reported that number of primary tillers per plant was increased with increasing of inter and intra-rows spacing and good management options. The widest plant spacing gave significantly higher tiller number and the narrowest spacing gave lower number of primary tillers. This is due to the fact that, as space among plants and good soil management practices increased ample resources become available for each plant that enhances the lateral vegetative growth of the crop. In agreement with this result, Mehmet (2008) who reported that increased number of primary tillers due to wider plant spacing for soybean. Similarly, Khalil *et al*. (2010) and Yucel (2013) also reported there was a trend that number of primary tillers was increased as the space among plants increased compared to plants at narrow spacing.

4.3.3. Plant height

Plant height was significantly affected by the main effect of plant density and weeding management practices ($p \leq 0.05$) but not by the interaction effect of these treatments (Table9).

Table 9. The main effects of plant spacing and weed management practices on plant height PH (cm) for faba bean during the growing season

Spacing	PH (cm)
45cm x 5cm	133.1 [a]
40cm x10cm	124.1 [b]
35cm x15cm	119.4 [b]
LSD (5%)	5.164
Weed management	
Weedy check	131.7 [a]
Gallant super	127.9 [a]

Fusillade	123.8 [ab]
Hand weeding	118.8 [b]
LSD (5%)	5.96

Means of the same category followed by different letters are significantly different at 5% probability.

The longest plant height (133.1cm) was recorded in plant spacing of 45 cm × 5 cm while the shortest plant height (119.4 cm) was recorded in 35 cm x 15 cm plant spacing. This was probably due to the competition of plants in higher densities for light, resulting in taller plants. Similar findings were reported by Singh *et al.* (2002), Khalil *et al.* (2015) and Almaz and Kindie, (2017) indicated that the denser plant population increased the plant height of faba bean due to competition among plants. Similary, Taj *et al*. (2002) reported that more competition for light in narrow spacing that resulted in taller mung bean plants while at wider spacing light distribution was normal. Likewise, Shamsi and Kobraee (2009) reported that decreased spacing among plants (increase density of plants) led to significant increases in plant height of soya bean (Hailu *et al*., 2019).

Weedy check plots resulted in longer plant height (131.7 cm) than hand weeding but statically similar with gallant super and fusillade herbicides application (Table 9), whereas, hand weeding treatment recorded in the shortest plant height (118.8 cm). In agreement with this result, Mengesha *et al.* (2015) reported that plants, which were kept weed-free throughout the season, were significantly shorter than the plants in plots in weedy check and once weeded at three or four WAE. The authors asserted this to no or little competition posed by the weeds resulting in stouter and thicker or sturdy plants. El-Metwally *et al.* (2017) indicated that hoeing twice was superior treatment for enhancing plant height. Such enhancements due to weeded treatments might be attributed to their high efficiency in inhibition of weeds and consequently, decreased their competitive with faba bean plants. In addition, the hand hoeing method led to improve soil physical characteristics including hydraulic conductivity, porosity and soil aeration, which favored the nutrient availability in soil.

4.3.4. Total leaf area

Analysis of data revealed that the main effect of plant spacing and weed management practices significantly affected total leaf area (TLA). However, this parameter was not affected by the interaction of these treatments (Table10).

Table 10. The main effects of plant spacing and weed management practice on TLA (cm^2) and LAI for faba bean during the growing season

	TLA	LAI
Spacing	(cm^2)	-
45cm x 5cm	1322 [a]	5.875 [a]
40cm x10cm	1275 [b]	3.188 [b]
35cm x15cm	1172 [c]	2.232 [c]
LSD (%)	27.27	0.062
Weed management		
Hand weeding	1292 [a]	3.858 [a]
Weedy check	1259 [ab]	3.777 [ab]
Gallant super	1249 [b]	3.745 [bc]
Fusillade	1224 [c]	3.679 [c]
LSD (%)	31.49	0.071

Means of the same category followed by different letters are significantly different at 5% probability

The maximum total leaf area (1322 cm^2) was recorded for crop sown on 45 cm x5 cm plants spacing, while lowest total leaf area (1172 cm^2) was recorded at 35 cm x15 cm plant spacing. Maguje Masa *et al*. (2017) reported, as intra row spacing increases, the leaf area of Common Bean (*Phaseolus vulgaris* L.) increases. This might be due to low amount of resources for leaf area increment under crowding density with narrow spacing which reduces ground cover area of a plant. Similarly, Mekonnen SA (2003) reported that as plant density increased, leaf area and leaf number decreased on common bean. Maqboola *et al*. (2006) and Ukonze *et al.* (2016) reported that wider spacing encouraged highest vegetative growth of maize. Plant leaf area was affected significantly as observed between the highest and lowest populations. The highest leaf area of maize was produced by treatment of wider plant spacing while narrow plant spacing treatment produced the lowest leaf area. The leaf area reduced with closer plant density which confirmed that stand architecture alters growth and development patterns of maize (Baron *et al*., 2006; Raemaker, 2011).

The maximum total leaf area (1292 cm^2) was recorded from hand weeding management while the lowest (1224 cm^2) was recorded by plot treated with fusillade herbicide. It was 1249 cm^2 by gallant super herbicide and 1259 cm^2 on weedy check plot. The largest value of total leaf area from twice hand weeding management may be due to the longer and wider leaves and due to the increased plant biomass. In addition, more number of stands due to higher tiller capacity in hand weeded plots led to an increase in the number of leaves and thereby increases the total leaf area. The lower values of total leaf area due to chemical herbicides may be due to shorter and narrower leaves results from the impacts from foliar applications

4.3.5. Leaf area index

Leaf area index (LAI) was significantly affected by spacing and weed management practice. The interaction effect of these treatments did not affect the LAI (Table 10).The highest LAI (5.875) was obtained in the 45 cm x 5 cm inter and intra row spacing. While the lowest values (2.232) was obtained from 35 cm x 15 cm spacing. Worku and Demisie (2012) reported that a large leaf area index at high plant density might attribute to improved light interception thus, ensuring high biomass and yield than at low plant density. Gezahegn *et al*. (2016) and Almaz Meseret and Kindie Tesfaye (2019) indicated that the highest LAI was obtained in narrowest intra row spacing, while the lowest was found in widest intra row spacing. In contrast to this, they found that the highest LAI was obtained in the narrowest inter row spacing while the lowest was for the widest spacing. The rate of increase of leaf area determines the rate of increase in the photosynthetic capacity of the plant. This was probably due to decrease in ground area intra-row spacing was decreased (Almaz Meseret and Kindie Tesfaye, 2019).

The maximum leaf area index (3.858) was recorded in hand weeding followed by weedy check (3.777). The lowest LAI (3.679) was obtained from the application fusillade and followed by for Gallant super herbicide (3.745). El-Metwally *et al*. (2017) indicated that hoeing twice was superior treatment for increasing LAI. In addition, the hand hoeing method led to improve soil physical characteristics including hydraulic conductivity, porosity and soil aeration, which favored the nutrient availability in soil (El-Metwally *et al*., 2017). The lower values of leaf area index due to chemical herbicides may be due to lower values of total leaf area obtained under these treatments as discussed above.

4.4. Yield and Yield Components

The main effect of plant spacing and weed management practices on yield components is presented as in Table 11 below.

Table 11. The main effects of plant spacing and weed management practices on yield components for faba bean during the growing season

Spacing	NPdPP	NSPPd	HSW (gm)	Spacing	DBW (Kg ha^{-1})
35cm x 15cm	31.27 ᵃ	2.714 ᵃ	59.39 ᵃ	45cm x 5cm	12648 ᵃ
40cm x 10cm	23.85 ᵇ	2.655 ᵃᵇ	58.42 ᵃᵇ	40cm x 10cm	7819 ᵇ
45cm x 5cm	21.63 ᵇ	2.539 ᵇ	56.98 ᵇ	35cm x 15cm	5623 ᶜ
LSD (5 %)	3.996	0.17	2.190	LSD (%)	648.167
Weed management					
Hand weeding	35.08 ᵃ	2.938 ᵃ	62.17 ᵃ	Hand weed	10560 ᵃ
Fusillade	26.13 ᵇ	2.717 ᵇ	58.97 ᵃᵇ	Fusillade	9118 ᵇ
Gallant super	21.78 ᵇᶜ	2.563 ᵇ	57.14 ᵇᶜ	Gallant super	8131 ᵇ
Weedy check	19.33 ᶜ	2.327 ᶜ	54.78 ᶜ	Weedy check	6980 ᶜ
LSD (5 %)	4.614	0.135	2.529	LSD (%)	790.008

NPdPP = Number of pods per plant NSPPd = Number of seeds per pod, HSW = Hundred seeds weight, DBW = Dry biomass weight. Means of the same category followed by different letters are significantly different at 5% probability.

4.4.1. Number of pods per plants

Number of pods per plant was significantly affected by the main effects of plant spacing and weed management options but not by the interaction effect of these treatments (Table 11).The maximum number of pods per plant (31.27) was recorded by 35cm x 15 cm spacing and the minimum number of pods per plant (21.63) was observed by 45cm x 5cm spacing. This value was 23.85 for 40cm x 10cm plant spacing. In line with this result, Melak (2014) and Hailu *et al.* (2019) reported the highest number of pods plant^{-1}at wider spacing as compared to narrow spacing. The increment in number of pods per plant at the less dense population might be due to increase in net assimilation rate and reduction of competition in wider spacing. In addition, at wider spacing the growth factors (nutrient, moisture and light) for individual plants might be easily accessible that retained more flowers and supported the development of pods. Almaz Meseret and Kindie Tesfaye (2019) also found that the number of pods per plant was increased with increasing intra row spacing. According to their explanation, the result may be due to wide spaces between the plants attributed to decreased inter plant competition that leads to increased plant capacity for utilizing the environmental inputs in building great amount of metabolites to be used in developing new tissues and increasing its yield components. This result is in agreement with Al Suhaibani *et al.* (2013) and Khalil *et al*. (2015) who found the highest number of pods per plant in low plant density.

Twice hand weeding treatments provided the maximum values (35.08) in number of pods per plant as compared to the all other weeding treatment. The minimum number of pod per plant (19.33) was observed on weedy check plots. Fusillade was the next better treatment to promote number of pods per plant (26.13) followed by that of gallant super (21.78) herbicide treated plots (Appendix Table-III). Such superiority of these weeded treatments may be related with minimizing weed-crop competition. The positive effect of weeding practices on faba bean yields and its attributes have been confirmed by Abd El-Razik (2006), Abdelhamid and El-Metwally (2008), ElMetwally (2016), El-Metwally and Dawood (2016) and ElMetwally I.M. *et al*. (2017) indicated that two hand hoeing treatments provided the maximum values in number of pods/plant followed by using chemical herbicides than the un weeded check. Such superiority of these weeded treatments may be related with minimizing weed-crop competition this in turns increased faba bean growth and reflected on increasing the number of pods/plant of faba bean. Mengesha *et al.* (2015) reported higher number of pods plant^{-1} in weed-free check might be due to the absence of competition from weeds as the plots were kept weed-free throughout the cropping season. In addition, the development of more and vigorous leaves might have helped the crop to improve the photosynthetic efficiency that may have nourished large number of pods (Hodgson and Blackman, 2005). Early weeding at two WAE also enhanced number of pods plant^{-1}, which could be attributed to better competition of the crop for growth resources against weeds. Likewise, Ayaz *et al.* (2001) and Mengesha *et al.* (2015) stated that the number of pods produced per plant or maintained up to the final harvest depends on a number of environmental and management practices. Similar results were reported on chickpea (Rashid *et al*., 2009; Fathi *et al*., 2010; Tepe *et al*.,

2011) and mung bean (Khan *et al.*, 2008) where weed interference decreased the number of pods per plant

4.4.2. Number of seeds per pod

The number of seeds per pod was significantly affected by the main effect plant spacing and weed management practices but not the interaction of the two treatments (Table 11). The less dense the plant population (as the cases of 35cm x 15cm), the larger the number of seeds per pod (2.71) could be the growth factors (nutrient, moisture and light) for individual plants might be easily accessible that retained more flowers and supported the development of pods and thereby increase in the number of seeds per pods. These values were 2.655 and 2.539 by 40cm x 10cm and 45cm x 5cm spacing respectively. The result agrees with that of Mahmoud (2014) who reported that the number of seeds per pod of faba bean decreased with close planting. Similarly, Bakry *et al*. (2011) reported that the highest number of seeds per pod was obtained from the wider spaced plants compared to close spaced plants (Hailu *et al*., 2019).

The maximum number of seed per pod (2.938) was recorded under twice hand weeding management practices whereas the minimum number (2.327) of seed per pod was recorded with no weed treatment. Next to twice hand weeding, fusillade was better in increasing number of seeds per pods (2.717) than gallant super herbicide (2.563). In line with this, Mengesha *et al.* (2015) found that plants which were kept weed-free throughout the season had the highest number of seeds per pod, which is statistically at par with the number of seeds per pod from plants that were once hand weeded at two WAE as well as twice at two and five WAE.

4.4.3. Hundred seeds weight (HSW)

The main effect of plant spacing and weed management practices significantly affected hundreds seeds weight. However, this parameter was not affected by the interaction of these treatments (Table 11). The maximum weight of hundred seeds values (59.39gm) were recorded on 35cm x 15cm plant spacing and the minimum weight (56.98gm) were observed on 45cm x 5cm. It was58.42gm by plot having 40cm x 10cm spacing which was statically similar with 35cm x 15cm plant spacing. In conformity with the result, Hailu *et al*. (2019) found that hundred seed weight was significantly increased as spacing increased. This increment might be because of assimilates division between higher numbers of seed used in connection with the decreased inter plant competition that lead to increased plant capacity, for utilizing the environmental inputs in building great amount of metabolites to be used in developing new tissues and increasing its yield components (Hailu *et al*., 2019). Mahmoud (2014) also reported that seed weight of faba bean was significantly increased with wider plant spacing compared to the narrowest spacing.

The maximum 100 seeds weight (62.17gm) was obtained from twice weeding management practice and the minimum HSW was obtained from weedy checks (54.78). The two chemical herbicides were not statically different (Table 11). ElMetwally I.M. *et al*. (2017) indicated that two hand hoeing treatments provided the maximum values in seeds weight /plant, 100- seed weight and seed yield ton/fed as compared to the un weeded check. Such superiority of these weeded treatments may be related with minimizing weed-crop competition this in turns increased faba bean growth and reflected on increasing the yield of faba bean. The positive effect of weeded practices on faba bean yields and its attributes have been confirmed by Abd El-Razik (2006), Abdelhamid and El-Metwally (2008), El-Metwally (2016) and El-Metwally and Dawood (2016).

4.4.4. Dry biomass weight

The dry biomass weight (ton ha^{-1}) was significantly affected by the main effect of plant spacing and weed management practices used. However, it was not affected by the interaction of these treatments(Table 11).The highest total dry biomass weight (12648kg ha^{-1}) was recorded by45cm x 5cm spacing while the minimum dry biomass weight (5623kg ha^{-1}) was obtained from 35cm × 15 cm plant spacing. In line with this result, Solomon (2003) reported that above ground dry biomass yield per ha was significantly increased with decreasing plant spacing on soy bean. Similarly, Derogar (2014) and (Hailu *et al*., 2019) reported that increasing plant density resulted in increased biological yield of faba bean. These findings were also in agreement with Badawy (2011) who stated biological and seed yields were significantly increased with increasing plant density. Worku and Demisie (2012) also reported that a large leaf area index at high plant density might attribute to improved light interception thus, ensuring high biomass and yield than at low plant density.

The dry highest biomass weight (10560kg ha^{-1}) was recorded from twice hand weeding while the lowest (6980 kg ha^{-1}) was recorded on weedy checks. There were no statically differences between fusillade and gallant super herbicide treatments on dry highest biomass weight. These values were 9118kg ha^{-1} by fusillade and 8131kg ha^{-1} with gallant super herbicides. El-Metwally, I. M. *et al.* (2017) indicated that hoeing twice was superior treatment for increasing dry weight/plant. Such enhancements due to weeded treatments might be attributed to their high efficiency in inhibition of weeds and consequently, decreased their competitive with faba bean plants. In addition, the hand hoeing method led to improve soil physical characteristics including hydraulic conductivity, porosity and soil aeration, which favored the nutrient availability in soil (El-Metwally, I. M. *et al.*, 2017).

4.4.5. Grain yield

Table 12.Interaction effect of spacing and weed management practices on Grain Yield (kg/ha) for faba bean during the growing season

Spacing	Weed management	GYL
45 cm x5cm	Hand weeding	6401 [a]
45 cm x5cm	Fusillade	6181 [ab]
45 cm x5cm	Gallant super	5723 [b]
45 cm x5cm	Weedy check	4567 [c]
40cm x10cm	Hand weeding	4469 [c]
40cm x10cm	Fusillade	3433 [d]
40cm x10cm	Gallant super	3102 [de]
35cm x15cm	Hand weeding	2902 [d-f]
40cm x10cm	Weedy check	2590 [e-g]
35cm x15cm	Fusillade	2382 [f-h]
35cm x15cm	Gallant super	2076 [gh]
35cm x15cm	Weedy check	1820 [h]
LSD (0.05)		545.534
CV (%)		8.5

Means of the same category followed by different letters are significantly different at 5% probability

The greatest grain yield (GYL) (6401 kg ha^{-1}) was obtained as a result of twice hand weeding treatment with 45 cm × 5 cm plant spacing. The lowest (1820 kg ha^{-1}) was recorded from weedy check plot and with 35cm × 15 cm spacing. The grain yield (GYL) obtained as a result of twice hand weeding and 45 cm × 5 cm plant spacing was not statistically different with the yield (6181 kg ha^{-1}) obtained by fusillade herbicide on 45 cm x5cm spacing. The grain yield (kg ha^{-1}) obtained on 45 cm x5cm spacing with weedy check (4567 kg ha^{-1}) and 40cm x10cm by hand weeding (4469 kg ha^{-1}) were statically similar. This result was in conformity with the finding by El-Metwally I.M. *et al*. (2017) who indicated that the lowest seed yield/fed was recorded from the un weeded treatment with sowing faba bean at the lowest plant population plants/fed. Accordingly, seed yield/fed was recorded from sowing faba bean at higher plant population plants/fed with two hand hoeing method treatment followed by the same plant population combined with chemical herbicide treatments than un weeded treatment. These results may be due to reducing competition for space, light, water and nutrients through limiting weeds infestation with herbicidal treatments; thus, increasing the uptake of different nutrients, which reflected on growth parameters and yield per unit area (El-Metwally I.M. *et al*., 2017).Badawy (2011) who stated biological and seed yields were significantly increased with increasing plant density m^{-2}. Similarly, Dahmardeh *et al*. (2010) reported higher biological yield in sandy loam soil in higher plant density due to an increase in the number of plants in the unit's area. He also stated that the highest and lowest seed yields were obtained with the highest and lowest plant density, respectively. Similarly, Al-Suhaibani *et al*. (2013) stated that when the planting density is too low each plant may perform at its maximum capacity, but there may be insufficient total plants to reach the optimum yield. Upon the relationships between plant density and yield, Mellendorf (2011) explained two concepts. First, maximum crop yield can only be achieved if the crop community can produce sufficient leaf area to provide maximum light interception during reproductive growth. Second, equidistant plant spacing maximizes yield because it minimizes plant to plant competitions. Therefore, the reduction in yield caused by high plant density could be due to the competition between plants for this treatment begins during early vegetative growth.

4.4.6. Harvest index (HI %)

Harvest index was significantly affected by plant spacing only but this parameter was not affected by weed management practices and the interaction of the spacing and weeding treatments (Table 13).

Table 13. The main effects of plant spacing and weeding management practice on harvest index (HI) for faba bean during the growing season

Spacing	HI (%)
45cm x 5cm	45.13 [a]
40cm x 10cm	43.58 [ab]
35cm x 15cm	41.06 [b]
LSD (0.05%)	2.365
Weeding	
Gallant super	44.29 [a]
Hand weeding	43.08 [a]
Fusillade	42.96 [a]
Weedy check	42.70 [a]
LSD (0.05%)	2.73 [ns]

Means of the same category followed by different letters are significantly different at 5% probability

Plots with 45cm × 5 cm plant population had resulted in a higher harvest index (45.1) but statically similar with 40cm x 10cm spacing. The lower value for harvesting index (41.06 %) was recorded under the low plant density (35cm x15 cm). On the contrary, Yucel (2013), Mahmoud (2014) and Teklu Haile and Solomon Ayele (2019) reported that the highest harvest index was recorded from the wider spacing. Getachew Mekonnen *et al.* (2017) also reported that higher plant population decreased harvest index due to drier biomass greater than the grain in Cowpea (*Vigna unguiculata* L.). Similar results were obtained by Weber *et al*. (1966) who reported that lower plant population tended to increase harvest index in soybean.

4.5. Economic Feasibility Analysis

The main effect of plant density, methods of weed management and the interaction of these two treatments significantly affected gross benefit and net benefit at (p= 0.05) (Table 14)

Table 14. The interaction effect of plant spacing and weed management practices on gross and net benefit gained for faba bean during the growing season

Spacing	**Weeding**	**NBT**(Birr ha^{-1})	**GBT**(Birr ha^{-1})
45cm x 5cm	Hand weeding	106019 ^{a}	128019 ^{a}
45cm x 5cm	Fusillade	105037 ^{a}	123617 ^{a}
45cm x 5cm	Gallant super	95179 ^{a}	114459 ^{a}
45cm x 5cm	Weedy check	74141 ^{b}	91341 ^{b}
40cm x 10cm	Hand weeding	69848 ^{bc}	89373 ^{b}
40cm x 10cm	Fusillade	52556 ^{cd}	68661 ^{c}
40cm x 10cm	Gallant super	45231 ^{de}	62036 ^{cd}
35cm x 15cm	Hand weeding	39431 $^{d-f}$	58049 $^{c-e}$
40cm x 10cm	Weedy check	37084 $^{d-f}$	51809 $^{c-f}$
35cm x 15cm	Fusillade	32452 ^{ef}	47650 $^{d-f}$
35cm x 15cm	Gallant super	25622 ^{f}	41520 ^{ef}
35cm x 15cm	Weedy check	22573 ^{f}	36391 ^{f}
LSD (5 %)		10910.69	10910.69
CV (%)		8.5	11.0

NBT = Net benefit GBT= Gross benefit. Means of the same category followed by different letters are significantly different at 5% probability

The maximum net benefit (106019 Birr ha^{-1}) was obtained by 45cm x 5cm and twice hand weeding which was statically similar to the net benefit (105037 Birr ha^{-1}) obtained by 45cm x 5cm spacing and fusillade, and by 45cm x 5cm spacing with Gallant super (95179 Birr ha^{-1}) herbicides. This was due to the higher grain yield recorded with the interaction effect of plant spacing and weed management practices under these treatments, in the same manner influenced the net benefit. The lowest net benefit (22573 Birr ha^{-1}) was obtained by35cm x 15cm spacing and Weedy check plot and the second lower value (25622 Birr ha^{-1}) was due to the application of gallant super herbicide on similar plant spacing. This might be because of lower grain yield as influenced by lower density and weed infestation.

From Table 14 above, the highest (128019 Birr ha^{-1}) gross benefit accrued from the combined use of 45cm × 5 cm plant spacing and twice weeding by hand treatment was 28.43% higher than the lowest gross benefit (36391 Birr ha^{-1}) obtained from the 35 cm × 15 cm plant spacing under the weedy check.

This was due to the lowest grain yield (1820 kg/ha) from weed competition of weedy check plot and having 35 cm x15 cm plant spacing. In agreement with this, Mengesha *et al*. (2015) indicated that the highest net benefit from the combined use of dense plant spacing and two weeding by hand-hoeing two and five WAE could be attributed to high yield and the low net benefit was attributed to low yield due to wider plant spacing and weed competition. From the economic point of view, it was obvious that combined use of 45 cm × 5 cm plant spacing and two weeding by hand was more profitable than the rest of the treatments.

5. SUMMARYAND CONCLUSIONS

The major problem facing the production of faba bean in Ethiopia are different diseases, insect pests and weeds. Faba bean is low competitive ability during its early stages of growth and thus uncontrolled weed populations can substantially reduce the yield up to 80-90% when they are not removed during critical period of competition. This study was initiated with an objective to evaluate effect of plant spacing and herbicide application on weed infestation, yield and yield components of faba bean (*vicia faba* L.).

The experiment was conducted with three inter- and intra-row plant spacing (35 cm × 15 cm, 40 cm ×10 cm, 45 cm ×5 cm), and four weeding options (gallant super and fusillade herbicides, twice hand weeding and weedy check). A randomized complete block design with three replications was employed in a factorial arrangement. Faba bean (Wolki variety) was used and the recommended fertilizer rate 100kg/ha of DAP was applied for all plots equally.

The most dominant grass weeds observed were; *Snowdenia polystachya Avena fatua*, and *Cyperus sculentus* according to their dominance respectively. From the result of the study, twice hand weeding was the most effective weed management option for faba bean in reducing weed density followed by using fusillade then gallant super herbicides treatments.

Days to 50% flowering were significantly decreased in 35 cm x 15 cm plant spacing treated with twice hand weed management practice. The days to 90% physiological maturity under twice hand weeding treated plot was earlier. Moreover, the number of days to physiological maturity was delayed due to increased weed competition in case of weedy check plots than over other treatments.

The maximum numbers of pods per plant, the highest number of seeds per plant, and the largest weight of hundred seed were recorded by 35cm x 15 cm spacing and the minimum number of pods per plant, the lowest number of seeds per plant and the smallest weight of hundred seed were observed by 45cm x 5cm spacing. Moreover, twice hand weeding treatments provided the maximum numbers of pods per plant, the highest number of seeds per plant and the largest weight of hundred seed as compared to the all other weeding treatment. The greatest grain yield was obtained due to the interaction effect of twice hand weeding treatment and 45 cm × 5 cm plant spacing. The lowest was recorded from weedy check plot and with 35cm × 15 cm spacing. The results might be due to reducing competition for space, light, water and nutrients through limiting weeds infestation with weed control treatments; thus, increasing the uptake of different nutrients, which reflected on growth parameters and yield per unit area

Generally, from the findings of this study, the researcher concluded that parameters like days to flowering and number of tillers per plant were enhanced by using lesser plant density treated with hand weeding management. Days to maturity, NPdPP, NSPPd and HSW preferred either wider plant spacing or hand weeding management than using either closer spacing or use of herbicide weed or left weedy check plots of weed managements. Otherwise for maximizing dry biomass (kg/ha), grain yield (kg/ha) and net return from production of faba bean closer plant spacing treated with hand weeding managements would be best choice.

Finally the author recommended that the study should be tested on different agro ecological and farmers' site conditions with varies combination and integration of weed management options, different inter and intra row spacing combinations and appropriate and preferred herbicide selections so that to come up with the best choice for enhancing production and productivity of faba been and thereby optimizing net returns specifically for the producer and the country in general in the sector.

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7. APPENDICES

Appendix-Tables

Appendix-Tables I. The main effect of plant spacing and weeding practices on days to 50% flowering (DTF) for faba bean during the growing season

Spacing	**DTF**
45cm x 5cm	53.42 a
40cm x10cm	52.92 ab
35cm x 15cm	52.50 b
LSD (0.05)	0.415
Weeding	**DTF**
Weedy check	53.44 a
Gallant super	53.11 ab
Fusillade	52.78 bc
Hand weeding	52.44 c
LSD (0.05)	0.479

Means of the same category followed by different letters are significantly different at 5% probability

Appendix-Tables II. The main effect of plant spacing and weeding practices on number of tillers per plant (NTPP) for faba bean during the growing season

Spacing	**NTPP**
35cm x 15cm	1.646 a
40cm x 10cm	1.538 a
45cm x 5cm	1.262 b
LSD (0.05)	0.199
Weeding	**NTPP**
Hand weeding	2.411 a
Fusillade	1.317 b
Gallant super	1.178 b
Weedy check	1.021 b
LSD (0.05)	0.230

Means of the same category followed by different letters are significantly different at 5% probability

Appendix-Tables III. The main effect of plant spacing and weeding practices on Grain yield (GYL) for faba bean during the growing season

Spacing	**GYL(Kg/ha)**
45cm x 5cm	5718 a
40cm x 10cm	3398 b
35cm x 15cm	2295 c
LSD (0.05)	272.77
Weed management	**GYL(Kg/ha)**
Hand weeding	4591 a
Fusillade	3999 b
Gallant super	3634 b
Weedy check	2992 c
LSD (0.05)	314.96

Means of the same category followed by different letters are significantly different at 5% probability

Appendix-Tables IV. The main effect of plant spacing and weeding practices on Gross and Net benefits for faba bean during the growing season

Spacing	**NBT(Birr/ha)**	**Spacing**	**GBT(Birr/ha)**
45cm x 5cm	95094 a	45cm x 5cm	114359 a
40cm x 10cm	51180 b	40cm x 10cm	67970 b
35cm x 15cm	30020 c	35cm x 15cm	45902 c
LSD (%)	5455.34		5455.34
Weed management	**Mean NBT**	**Weed management**	**Mean GBT**
Hand weeding	71766 a	Hand weeding	91814 a
Fusillade	63348 ab	Fusillade	79976 b
Gallant super	55344 b	Gallant super	72672 b
Weedy check	44599 c	Weedy check	59847 c
LSD (%)	6299.29		6299.29

Means of the same category followed by different letters are significantly different at 5% probability

Appendix-Tables V. Mean square from analysis of variance for phenological parameters for faba bean during the growing season

Source of variation	d.f.	Mean square	
		DTF	DTM
Replication	2	0.3611ns	0.5278ns
Treatments			
Spacing	2	2.5278**	10.77788**
Weeding	3	1.6667**	2.9630**
Spacing * Weeding	6	0.6389*	0.4074ns
Error	22	0.2399	0.3157

Appendix-Tables VI. Mean square from analysis of variance for yield and related parameters for faba bean during the growing season

Source of variation	d.f.	Mean square					
		NPdPP	NSPd	HSW	DBW	GYL	HI
Replication	2	5.26ns	0.02351ns	6.085ns	120391ns	288746*	10.246ns
Treatment							
Spacing	2	305.84*	0.09509*	17.610*	154990359**	36626031**	50.600*
Weeding	3	431.98**	0.59563**	87.395**	20752344**	4033952**	4.476ns
Spacing * Weeding	6	8.83ns	0.00326ns	0.183ns	728474ns	254757*	4.793ns
Error	22	22.28	0.01906	6.692	652997	103794	7.800

Appendix-Tables VII. Mean square from analysis of variance for growth and related parameters for faba bean during the growing season

Source of variation	d.f.	Mean square					
		NSBT	NSBH	NTPP	PH	TLA	LAI
Replication	2	20.03ns	411.7ns	0.01066ns	30.11ns	6600*	0.036253**
Treatment							
Spacing	2	18664.53**	15282.8**	0.47081*	578.65**	70920**	42.804821**
Weeding	3	5.26ns	29069.5**	3.58666**	278.41**	7173**	0.049906**
Spacing * Weeding	6	5.45ns	403.4ns	0.21947**	8.15ns	918ns	0.003248ns
Error	22	19.97	723.0	0.05534	37.20	1037	0.005341

Appendix-Tables VIII. Mean square from analysis of variance for cost- benefit analysis for faba bean during the growing season

Source of variation	d.f.	Mean square	
		Gross benefit	Net benefit
Replication	2	1.155E+08*	1.155E+08*
Treatments			
Spacing	2	1.465E+10**	1.322E+10**
Weeding	3	1.614E+09**	1.207E+09**
Spacing * Weeding	6	1.019E+08*	1.019E+08*
Error	22	4.152E+07	4.152E+07