

**INFLUENCE OF PLANT POPULATION AND WEED MANAGMENTON
GROWTH AND YIELD OF FABA BEAN (*Vicia faba*L.) IN OMONADA DISTRICT,
SOUTHWESTERN ETHIOPIA**

M.Sc. THESIS

BY

ASFAW EMBABO MARU

**February /2020
Jimma, Ethiopia**

**INFLUENCE OF PLANT POPULATION AND WEED MANAGMENT ON
GROWTH AND YIELD OF FABA BEAN (*Vicia faba*L.) IN OMONADA DISTRICT,
SOUTHWESTERN ETHIOPIA**

M.Sc. Thesis

**Submitted to Post Graduate Program, Jimma University, College of Agriculture and
Veterinary Medicine, in Partial Fulfillment of the Requirements for the Degree of Master
of Science in Agriculture (Agronomy)**

**February/2020
Jimma, Ethiopia**

APPROVAL SHEET

Jimma University College of Agriculture and Veterinary Medicine

Thesis Submission Request Form (F-08)

Name of student: Asfaw Embabo ID.No. RM1384/09

Program: MSc. in Agronomy

Title: Influences of plant population and weed management on growth and yield of faba bean (*Vicia faba*L.) in Omo Nada district, Southwestern Ethiopia.

I have completed my thesis research work as per the approved proposal and it has been evaluated and accepted by my advisors. Hence, I kindly request the department to allow me to present the findings of my work and to submit the thesis.

Asfaw Embabo _____

Name of student

Signature of student

We, the thesis advisors have evaluated the contents of this thesis and found it to be satisfactory, executed according to the approved proposal, written according to the standards and formats of the University and is ready to be submitted. Hence, we recommend the thesis to be submitted.

Major Advisor: Gezahegn Barecha(Professor) _____ February 2020

Name

Signature

Date

Co-Advisor: Wakuma Bayissa (PhD) _____ February2020

Name

Signature

Date

Internal Examiner (if depends on the verdict)

Name: _____ Signature _____ Date _____

Decision/suggestion of Department Graduate Council (DGC)

Chairperson, DGC

Signature

Date

Chairperson, CGS

Signature

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DEDICATION

This Thesis is dedicated to my family for their dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

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

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Name Asfaw Embabo Maru Signature_____

Place: Jimma University, Jimma

Date of submission_____

ACKNOWLEDGEMENTS

First and foremost, it is an overwhelming excitement to come to this final point to express my deepest gratitude to all individuals and organizations who contributed in one way or another to my study. First of all, I would like to thank the CASECAPE project in Jimma University who made the study successful through the fund grants. I extend my gratitude to both my advisors Professor Gezahegn Barecha and Dr. Wakuma Bayissa for their utmost cooperation, encouragement and motivation, constructive suggestions and guidance, insightful and constructive comments, valuable criticism and endless support right from the planning stage of the research work to the write up of this Thesis. I also would like to sincerely thank both my advisors for their whole-hearted follow up, support and unreserved guidance as they have devoted much of their time in critically reading and commenting the manuscripts starting from the proposal development to the end of the thesis, in spite of their busy schedule and conducting a research work respectively.

Last but not least, I take this opportunity to give words of thanks to all other individuals and organizations, numerous to mention, who contributed their best to this work in various ways. I have not exhaustively listed the names of individuals and organizations that assisted me directly or indirectly during my course and research work.

ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
CIMMYT	International Maize and Wheat Improvement Center
CIAT	International Center for Tropical Agriculture
CSA	Central Statistics Agency
DAE	Days After Emergence
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Food and Agricultural Organization Statistical Division
IPM	Integrated Pest Management
IWM	Integrated Weed Management
JARC	Jimma Agricultural Research Center
LAI	Leaf Area Index
LSD	Least Significance Difference
MARR	Minimum Acceptable Rate of Return
Masl	Meters above sea level
MRR	Marginal Rate of Return
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System

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ABSTRACT

*Faba bean (*Vicia faba* L.) is among the leading legumes in area coverage and production in Ethiopia. However, its productivity is low mainly due to inappropriate plant population and weed management. Studies on the combined use of inter row spacing and weed management for faba bean are lacking at Omo nada area. Therefore, a field experiment was conducted to determine the effect of inter rows spacing and weed management on yield and yield components of faba bean in 2018 main cropping season in Jimma Zone, Omo Nada district, south western Ethiopia. Four inter row spacings ; 30 cm x 10 cm (333,333 plants ha⁻¹), 40cmx10cm (250,000 plants ha⁻¹), 50cm x 10cm (200,000 plants ha⁻¹) and 60 cm x 10cm (166,667 plants ha⁻¹) and five weeding regime ; no weeding, one time hand weeding at 20 days after emergence(DAE),two times hand weeding at 20 and 40DAE, three times hand weeding at 20,40 and 60DAE and application of Dual Gold pre-emergence herbicide at a rate of 1.00kg ha⁻¹ supplemented by hand weeding at 40DAE were laid out in a randomized complete block design with factorial arrangement in three replications. Data on weed density and dry weight, crop growth, yield and yield components of faba bean variety Tumsa were subjected to ANOVA using SAS version 9.3 software. The results revealed that interaction effect of inter rows spacing and weed management significantly ($P < 0.05$) affected weed density and dry matter, leaf area, leaf area index, plant height, number of pods per plant, number of seeds per pod, thousand seed weight, grain yield and above ground biomass of faba bean. However, days to 50% flowering, days to 90% maturity, height to first pod, Number of productive tillers per plant were not affected by interaction effect of inter rows spacing and weed management . The highest grain yield (3911.7 kg ha⁻¹) and above ground biomass (10589.7 kg ha⁻¹) was obtained from widest inter rows spacing (60cm) and twice hand weeding at 20 and 40DAE. Whereas, the lowest grain yield (1984 kg ha⁻¹) was recorded for narrowest inter row spacing (30cm) or 166667 plants ha⁻¹ and unweeded plot and the lowest above ground biomass (5874.6 kg ha⁻¹) was obtained from combined application of 50cm inter row spacing or 200000 plants ha⁻¹ with unweeded. Grain yield was strongly and positively correlated with plant height, leaf area, crop biomass, Number of productive tillers per plant, number of pod per plant, number of seeds per plant and harvest index, however it was strongly and negatively correlated with weed density and weed dry weight. Partial*

budget analysis revealed that combined application of 60cm inter row spacing or 166,667plants ha⁻¹ with twice hand weeding at 20 and 40DAE resulted in maximum net return (66,817ETBha⁻¹) with marginal rate of return of 3125%. Thus, 60cm inter row spacing or plant density of 166,667 plants ha⁻¹ and twice hand weeding was found to be better both agronomically and economically for faba bean variety Tumsa production under rain-fed conditions in the experimental area.

Keywords: Grain yield, Hand weeding, Plant density

1. INTRODUCTION

Globally, faba bean (*Vicia faba* L.) is the fourth food legume in terms of production after garden pea, chickpea and lentil (FAOSTAT, 2014). It also generates household income for the farming community. Ethiopia is the fourth largest exporting country of faba bean next to France, Australia and United Kingdom (FAOSTAT, 2014). The contribution of this crop to the country's economy in 2013/2014 crop season in terms of area coverage and production to the total national crop area under faba bean cultivation and production was about 4.34 % (about 538,458.21 hectares) and 3.94% (about 991,700.28 tone), respectively (CSA, 2014).

In 2014/2015 Crop season, about 3.8million farmers produce on 0.443 million hectare with estimated average productivity level of 1.9 ton/ha(CSA, 2015).Faba bean ranked first among cool season food legumes based on area production and foreign exchange earnings (CSA, 2016). The average national productivity of faba bean 2.1 t ha⁻¹(CSA, 2017) is low as compared to UK the world top producer 3tonha⁻¹ (Winch .2006)

Faba bean is grown at altitudes ranging from 1300 to 3800 m.a.s.l, but mostly grown from 2000 to 2500 m.a.s.l (Getachew and Chilot, 2009). The crop is well adapted to diverse soil types of Ethiopia where legumes are prominently used as traditional soil fertility maintenance crops in mixed cropping systems. It has also a great contribution for sustainable soil fertility management due to its ability to fix atmospheric N₂ (Beck *et al.*1991).

Fababean is used as an effective break crop in cereal rotations since it substantially improves soil fertility through biological nitrogen fixation. Which contribute to agricultural sustainability (Agegnehu, 2006; FAOSTAT, 2014).Moreover, it produces seeds with high protein content frequently exceeding 20-41% and considered as meat and skim-milk substitute (Creponaet *al.*, 2010).

The production and productivity of faba bean is constrained by several biotic and abiotic stresses of which lack of improved varieties, Optimum plant density and appropriate weed management, shortage of certified seeds, diseases such as rust, powdery mildew and root rot, insect pests such as aphids and low soil fertility, acidity of the soil in high rainfall areas and

low existence of effective indigenous rhizobia are the major ones becoming a major challenge to food security (Degife and Kiya, 2016).

Among these planting density affects the growth, development and grain productivity per unit area. Plant density has a remarkable capacity to exploit the environment with varying competitive stresses. High plant density or narrower spacing may cause lodging, less light penetration in the crop canopy and reduced photosynthetic efficiency and can reduce the yield drastically; In contrast, low plant density or wider spacing may result in low yield, more weed infestation and poor radiation-use efficiency (Lemerle *et al.*, 2006). It has been reported that among various package of improved production technologies proper plant population with appropriate adjustment of inter and intra row spacing play key role in enhancing faba bean production (Gezahegnet *al.*, 2016). Optimum plant density differs with variety and at different locations, since different locations have different soil type, soil moisture, soil fertility and relative humidity (Elhage *et al.*, 2014).

The other yield limiting factors include, poor weed management in addition to poor soil fertility, untimely sowing, and lack of improved varieties (Ghizaw and Molla, 1994). Faba bean is a very sensitive crop to competition of both broadleaf and grass weed species (Getachew and Rezene, 2006). The extent to which faba bean yield is reduced by weeds depends on weed species, density and on the period for which the crop is exposed to weeds. Therefore, inadequate and untimely weed control operation is one of the crucial factors causing low yields of the crop (Gezahegnet *al.* 2016).

Weeds can cause substantial losses to faba bean production when they are not removed during critical period of competition. The critical period of weed competition varies from 3 to 8 weeks after crop emergence. The numerous weeds affecting these crops are ranging from broad leaves to both annual and perennial grasses. Major weeds in faba bean crops are managed with hand weeding or by spraying herbicides. Two times hand weeding during 3-4 weeks and 6-8 weeks after emergence are very essential for faba bean production (EIAR, 2018).

Against annual and broad-leaved weeds, suitable preemergence herbicides are: Terbutryn (Igram 500 FW) at a rate of 2 kg a.i. ha⁻¹ and mixture of Terbutryn + Terbutlazine (Topogard

500 FW) at the rate of 2 kg a.i. ha⁻¹, Fluazifop-butyl (Fusilade 250 g/l EC) at 0.25 kg a.i. ha⁻¹ which are applied as post-emergence treatment to control late emerging annual grass weeds (EIAR, 2018). A field experiment was carried out in 1974 to determine the critical period in faba bean, the critical period of weed competition occurred from the 3rd to the 5th week after 50% crop emergence and when weeds were not controlled seed yield was reduced by 46% (Glasgow et al., 1976).

In Jimma Zone during 2015/2016 and 2016/2017 cropping season, production of faba bean in terms of area tended to increase from 20,194 to 20,704 hectares and also increased in total production and productivity from 368,542 to 414,417 tons and 1.825 to 2 tons per hectare, respectively (CSA, 2016 and 2017). Despite the potential of the zone, productivity of the crop was below the national average productivity (2.1 tons ha⁻¹) (CSA, 2017) and also below the potential productivity which is estimated to be more than 5 tons per hectares (Crop variety registration year book, 2016).

This indicates that productivity of the crop is still far below its potential due to lack of area specific scientific recommendations for optimum plant density and weed management. As a problem, not having optimum plant population and poor weed management practices are the major yield reducing factors in faba bean production by small scale farmers particularly at Omo Nada district.

Those farmers who engaged in faba bean production have poor access to information and practices for adopting proper plant population with appropriate adjustment of inter and intra row spacing and weed management options to boost productivity. Farmers usually control weeds by cultural methods particularly hand weeding. Farmers' access to herbicide to control weed in legumes including faba bean was not common to the study area. Due to such reasons, hand weeding is the common cultural practice to remove weed from pulse crops including faba bean. A few model farmers are hoeing in addition to hand weeding (hand pulling) to reduce weed pressure in faba bean. On the other hand, most farmers do not control weed timely until pod setting stage due to competitions for labor resources between agricultural activities.

Seed size of faba bean varieties determines the amount of seed needed per hectare. Those which have small seed size are sown at a rate of 150-175 kg/ha while those with large size require 200-250 kg/hectare. As well the germination percentage should be above 85% and genetic purity is 95%. Proper seed depth and soil moisture content results good germination and finally gives high yield. As a faba bean package recommendation respect to spacing between row 40cm, distance between plant 10cm and seed depth 5cm to 7 cm depending on seed size and soil types allows adequate space for mechanical cultivation to control weeds(EIAR, 2018).

Lack of area specific research finding and established practical recommendations on optimum plant population and weed management practices at small scale farmer's level is a major yield limiting problem.

Therefore, to bridge the gap of area specific recommendation, experiment was conducted at *Chalalaka Donga Kebele* on farmer's field during 2018 main cropping seasons with the following objectives.

- To identify the effect of inter row spacing and weed management on weed density and weed dry biomass.
- To evaluate the effects of different inter row spacing and weeding regimes on growth, yield and yield components of faba bean.
- To identify the economic optimum combinations of inter row spacing and weed management on growth, yield and yield components of faba bean in Omonada District, Jimma Zone.

2. LITERATURE REVIEW

2.1. Faba Bean Origin, Taxonomy and World Distribution

Faba bean is assigned to the Central Asian, Mediterranean, and South American centers of diversity and believe to be a native to North Africa and southwest Asia, and extensively cultivated elsewhere (Zohary and Hopf, 2000).

Cubero (1974) postulated a Near Eastern center of origin, with four radi to Europe along the North African coast to Spain, along the Nile to Ethiopia, and from Mesopotamia to India (Hawtin and Hebblethwait, 1983). Secondary centers of diversity are postulated in Afghanistan and Ethiopia. Nowadays, faba bean is widely grown in temperate and subtropical regions and at higher altitudes in the tropics.

In tropical Africa, it is mainly found in East Africa, especially in Sudan and Ethiopia (Musa and Gemechu, 2006). The main producing countries of faba bean in the world are China, Ethiopia, Egypt and Australia in the decreasing order of their production potential (Hawtin and Hebblethwaite, 1983). According to these researchers production is mainly concentrated in the high altitudes of Ethiopia ranging between 1800-3000 m.a.s.l with annual rainfall ranges from 700 to 1100mm and has suitable environmental and soil conditions for highland pulse crops production. Faba bean is one of the oldest food legumes and has been cultivated since antiquity, mainly for human consumption.

Faba bean is cultivated for human consumption, cattle feeding and it is also used as green manure for the poor soils. The Chinese used them for food since 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 (Singh and Bhatt, 2012).

The wild progenitor and the exact origin of faba bean remain unknown. Several wild species (*Vicianarbonensis* L. and *V. galilaea* Plitmann and Zohary) are taxonomically closely related to the cultivated crop, but they contain $2n = 14$ chromosomes, whereas cultivated faba bean has $2n = 12$ chromosomes (Cubero, 1974). Although usually classified in the same genus *vicia* as the vetches, some botanists treat *vicia* as a separate monotypic genus as *Faba sativa* Moench (Zohary and Hopf, 2000).

Vicia faba is an annual herb with coarse and upright stems, unbranched 0.3 to 2 m tall, with one or hollowed stems from the base. The leaves are alternate, pinnate and consist of 2 to 6 leaflets each up to 8 cm long and unlike most other members of the Genus; it is without tendrils or with rudimentary tendrils. The plant flowers profusely but only a small proportion of the flowers produce pods. Flowers are large, white with dark purple markings, borne on short pedicels in clusters of 1-5 on each axillary raceme usually between the 5 and 10 nodes; 1-4 pods develop from each flower cluster, and growth is indeterminate though determinate mutants are available (Hanelt and Mettin, 1989).

About 30% of the plants in a population are cross-fertilized and the main insect pollinators are bumblebees. There is a robust tap root with profusely branched secondary roots. Based on seed size, two subspecies were recognized, *paucijuga* and *faba*. *Vicia faba* has a diploid ($2n$) chromosome number of 12, meaning that each cell in the plant has 12 chromosomes (6 homologous pairs). Five pairs are acrocentric chromosomes and one pair is metacentric (Hanelt and Mettin, 1989; Alghamdi, 2009).

2.2. Faba Bean Production and Importance in Ethiopia

Faba bean is very cold hardy but cannot take excessive heat during flowering. As faba beans mature, the lower leaves darken and drop, pods turn black and dry progressively up the stem (Hekneby *et al.* 2006; Singh *et al.* 2013). This annual legume grows best under cool, moist conditions. Hot dry weather is injurious to the crop, so early planting is important. Faba bean tolerates frost. Rainfall of 650 to 1000 mm per annum evenly distributed is ideal for faba bean (Gasim and Link, 2007; Abdel, 2008).

Medium textured soils are ideally suited for faba bean production. It prefers types of soil with pH ranging from neutral to alkaline (pH of 6.5 to 8.0) (Rajane *et al.*, 2012). Since the crop requires a good moisture supply for optimum yields, moderate moisture supply is necessary. Faba beans do not tolerate water logging. Moisture requirement is highest about 9 to 12 weeks after establishment (Subash and Priya, 2012). Faba bean is more tolerant to acid soil conditions than most legumes (Singh *et al.*, 2010). It also tolerates nearly any soil type; grows best on rich loams. They are considered to be the least drought resistant of legume crops; however, cultivars with high water use efficiency have been developed at ICARDA (Subash and Priya, 2012).

Faba bean is one of the most popular legumes which is tightly coupled with every life of Ethiopians and grown during the main season on both red and black soils primarily in Oromia, Amhara, Tigray, and SNNP regional states (IFPRI, 2010). It is grown at 1300–3800 meter above sea level; but mostly at 2000–2500 m (Musa and Gemechu, 2006).

Rust is the major production constraint below 1800 m, and frost above 3000 m. Faba bean requires an annual rainfall of 700–1000mm, of which more than 60% during the growing period. Faba bean has four main functions in agro-ecosystems: provision of protein rich food and feed; supplying N to agroecosystems by symbiotic N fixation with *Rhizobium* bacteria to increase soil fertility; Diversifying the crop system to reduce constraints on growth and yield by the other crops in the rotation; and reducing fossil energy consumption for crop production. Besides, faba bean is grown for green manure and can significantly increase the yields of cereal and other crops (Wani *et al.*, 1994).

Faba bean is an excellent crop for cropping systems because its unique ability to fix atmospheric N symbiotically which is heavily depends on the sufficient populations of effective rhizobia (Jensen *et al.*, 2010). It can accumulate N both from soil and the atmosphere (Rajan and Singh, 2012). Due to their indeterminate growth habit, faba beans continue assimilating N for a longer period, reaching about 315 kg N ha⁻¹ after 110 days (Singh and Bhatt, 2012a). The N concentration in the faba bean crop biomass was around 5% a few days before flowering; during the initial stages (30 days) of reproductive growth; the N concentration decline rapidly to c. 2.5–3%, due to the biomass accumulation rate being faster than the N assimilation rate, and the N concentration remained at this level until maturity

(Knaak et al., 1993). Faba bean accumulates N from N fixation at an increasing rate until initiation of the maturation process unless other factors such as water availability restricts the N fixation process earlier in growth (Anetoun and Prevost, 2005).

Faba bean is a common breakfast food in the Middle East, Mediterranean region, China and Ethiopia. The most popular dishes of faba bean are Medamis(stewed beans), Falafel (deep fried cotyledon paste with some vegetables and spices), Bissara (cotyledon paste poured onto Plates) and Nabet soup (boiled germinated beans) (Hawtin and Hebblethpait, 1983).

Sometimes faba bean was grown for green manure, but more generally for stock feed (Singh and Bhatt, 2012). Large-seeded cultivars are used as vegetable. Roasted seeds are eaten like peanuts in India. Straw from faba bean harvest fetches a premium in Egypt and Sudan and is considered as a cash crop. The straw can also be used for brick making and as a fuel in parts of

Sudan and Ethiopia (Hulse, 1994). Cultivated faba bean is used as human food in developing countries and as animal feed, mainly for pigs, horses, poultry and pigeons in industrialized countries (Singh and Bhatt, 2012a). It can be used as a vegetable, green or dried, fresh or canned (Gasim and Link, 2007).

2.3. Major Faba Bean Production Constraints in Ethiopia

Production bottlenecks for faba bean in Ethiopia are numerous and can be categorized as cultural, biotic and abiotic factors. Most Ethiopian farmers are of the opinion that pulses do not require best land, fertile soil, better seed bed preparation and better weeding practices. Diseases such as chocolate spot (*Hotrytishbae*), black root rot (*Fusariwnsolani*), Rust (*Urotnycesfabae*) and insect pests: African bollworm (*Helicoverpaannigera*) and aphids (*Acyrthosiphonpisum*) and abiotic factors: waterlogging, frost, hail damage, and poor soil fertility are the major faba bean production constraints in Ethiopia (Yohannes, 1997).

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Faba bean is an excellent crop for cropping systems because its unique ability to fix atmospheric N₂ symbiotically which is heavy depends on the sufficient populations of effective rhizobia (Jensen *et al.*, 2010). It can accumulate N both from soil and the atmosphere (Rajan and Singh, 2012). Due to their indeterminate growth habit, faba beans continue assimilating N for a longer period, reaching about 315 kg N ha⁻¹ after 110 days (Singh and Bhatt, 2012a). The N concentration in the faba bean crop biomass was around 5% a few days before flowering; during the initial stages (30 days) of reproductive growth; the N concentration decline rapidly to 2.5–3%, due to the biomass accumulation rate being faster than the N assimilation rate, and the N concentration remained at this level until maturity (Knaaket *al.*1993).

Faba bean accumulates N from N₂ fixation at an increasing rate until initiation of the maturation process unless other factors such as water availability restricts the N₂ fixation process earlier in growth (Anetoun and Prevost, 2005).

Faba bean is a common breakfast food in the Middle East, Mediterranean region, China and Ethiopia. The most popular dishes of faba bean are Medamis (stewed beans), Falafel (deep fried cotyledon paste with some vegetables and spices), Bissara (cotyledon paste poured ontoplates) and Nabet soup (boiled germinated beans) (Hawtin and Hebblethpiait, 1983).

Sometimes faba bean was grown for green manure, but more generally for stock feed (Singh and Bhatt, 2012a). Large-seeded cultivars are used as vegetable. Roasted seeds are eaten like peanuts in India. Straw from faba bean harvest fetches a premium in Egypt and Sudan and is considered as a cash crop. The straw can also be used for brick making and as a fuel in parts

of Sudan and Ethiopia (Hulse, 1994). Cultivated faba bean is used as human food in developing countries and as animal feed, mainly for pigs, horses, poultry and pigeons in industrialized countries (Singh and Bhatt, 2012a). It can be used as a vegetable, green or dried, fresh or canned (Gasim and Link, 2007).

Despite the immense economic and ecologic merits, the productivity of faba bean in Ethiopia is far below the potential due to a number of biotic and abiotic constraints, socioeconomic constraints in smallholder farms and inadequate technological interventions (Basha and Dembi, 2017). Shiferaw *et al.* (2013) also mentioned the productivity of faba bean is far below expected potential due to low input usage, natural disasters like snow storm, depletion of macronutrient from cultivable land and unavailability of essential nutrients such as phosphorus. The productivity of faba bean crop is also constrained by low soil pH associated with low P availability.

Acid soils occur widely in the highlands of Ethiopia where the rainfall intensity is high and the land has been under cultivation for many years. These soils have pH values of less than 5.5, which result in low faba bean yields compared to other faba bean growing areas of the country (Tadeleet *et al.*, 2016). The low yields in such soils could mainly be either due to the deficiency of nutrients, such as P, Ca and Mg (Berry *et al.*, 2003; Dodd and Mallarino, 2005), or toxicity of Al, Fe and Mn (Sharma *et al.*, 2004). As a result, P deficiency is one of the most widespread soil constraints in these soils. Furthermore, Getachew *et al.* (2005) reported that acid soils could expose faba bean to greater chocolate spot infection thereby reducing yield.

There is a reduction in the cultivated area and productivity of faba bean in many countries. Several adverse biotic and abiotic factors have been reported to this decline of which; failing of practicing optimum population per unit area, weeds and insect pests are the main biotic yield limiting factors in its production (Torres *et al.*, 2006; Pérez-de-Luque *et al.*, 2010). Frost is one of the abiotic stresses contributing for its low production. For example, in Ethiopian highlands 100% yield losses can be experienced especially with late planting as the plants are exposed to frost damage (Mola, 1996).

Among the biotic factors, the most damaging parasitic weed of faba bean is *Orobancherenata* which germinates in response to chemicals released by faba bean (Joel *et*

al., 2007). It is widespread in Mediterranean basin especially in northern Africa, Asia and southern and eastern Europe, attacking dicotyledonous crops, and losses of 50 to 80% have been reported in faba bean fields (Gressel et al., 2004).

In addition, faba bean is adversely affected by numerous fungal diseases. The major diseases are rust (*Uromycesviciaefabae*), black root rot (*Fusarium spp.*), downy mildew (*Peronosporaviciae*), ascochyta blight (*AscochytafabaeSpeg*) and chocolate spot (*Botrytis fabae*) (Hanounik and Robertson, 1989). These diseases resulting up to 90% yield loss in faba bean (Muehlbauer and Tullu, 1997). Chocolate spot (*Botrytis fabae*) is one of the economically important diseases that damage the foliage, limiting photosynthetic activity and reducing faba bean production (Torres et al., 2006).

2.4. Description of the faba bean (*Vicia faba* L).

Faba bean plants are distinctly annual with strong, hollow, erect stems bearing usually one or more basal branches arising from leaf axils. The number of branches per plant in the indeterminate faba bean lines was low during the early vegetative stage and increased, reaching the maximum at flowering stage then declining towards maturity (Silim and Saxena, 1992).

Faba bean is bushy, hardy annual which can grow up to 1.22m tall. It has square stems with leaves divided into leaflets. Pods are 15.24cm to 20.32cm long and often contains 3 to 6 seeds that can be white, yellow, green, or purple. Fava bean has white flowers with some black or brown spots. In large seeded varieties, 1 or 2 pods grow at each node whereas at small seeded types the number of pods per node can be as high as five. On average there are about 15 pods per stalk on large types and 60 pods on small seeded varieties. When stored under favorable conditions, most faba bean seeds will remain viable for a life expectancy of 3 years.

In optimum growing conditions, germination of faba bean seeds take about 10 to 14 days. Faba bean plants grow at a rate of around 1 node per week. Because stems are strong and upright, the plant can grow from 0.91m to 1.22m, tall depending on the variety. At the 8 to 10 node growth stage, when the plant is around 0.35m high, roughly 25% of the flowers will

produce pods which usually contain three to six seeds in each individual pod. *Vicia faba* shows a high degree of out crossing. Out crossing in faba bean vary widely and is between a minimum of 5% and maximum of 70%. The average reported is about 35% (Bond and Poulsen, 1983).

Faba beans are allogamous, or have a mixed mating system, with both crosspollination and self-pollination, but require insect pollinators to maximize seed set. If low numbers of bees are present, introducing commercial pollinating bees through the crop in a grid of at least 2 hives/ha can increase yield by 30–100%. About 30% of the plants in a population are cross-fertilized and the main insect pollinators are honeybees in Australia. (Patrick and Stoddard, 2010).

2.5. Effects of Plant Population on Growth and Yield of Faba Bean

Several faba bean investigators reported the dense planting resulted in decreases for seeds/pod, seeds/plant, seed weight/plant and seed index (Mokhtar, 2001). While, dense planting had no effect on seeds/pod and on seed index (Zeidan et al., 1990). However, Hassan and Hafiz, 1998 found that seed index was increased in the densest plant population. On the other hand, seed yield was increased by increasing plant density up to 26.7 plant m⁻² (AbouSalama and Dawood, 1994), up to 31.7 plant m⁻² (Mokhtar, 2001) up to 33 plant m⁻² (Abdel-Aziz and Shalaby, 1999) and up to 44.4 plant m⁻² (Hassan and Hafiz, 1998). However, Saxena and Stewart (1983) obtained the lowest seed yield from the highest dense planting (33 plant m⁻²). In addition, insignificant yield differences were found between 16.7 and 22.2 plant/m² and between 24 and 67 plant/m² (Teama, 1994)

Plant density has a remarkable capacity to exploit the environment with varying competitive stresses. High plant density or narrower spacing may cause lodging, less light penetration in the crop canopy, reduced photosynthetic efficiency and can reduce the yield drastically; in contrast, low plant density or wider spacing may result in low yield, more weed infestation and poor radiation-use efficiency (Yucel, 2013). It has been reported that among various package of improved production technology proper plant population with appropriate

adjustment of inter and intra row spacing play key role in enhancing faba bean production (Gezahegn et al.,2016).

Optimum plant density differs from each variety and location, since different location has different soil type, soil moisture, soil fertility and relative humidity .Plant density has been recognized as a major factor determining crop yield and is of a particular importance for larger seeded varieties (Matthews et al., 2001). Optimum plant density and suitable plant arrangement per unit area allow crops to exploit resource optimally and produce high yields (Squire, 1993).

However, optimum plant density varies depending on crop species or due to varietal difference in vigor, height and branching, time of sowing, and the nature of the season (Anderson, 2004). The response of crops to plant density tended to be less in the low as compared to the high yielding environments (Matthews et al., 2001). This can also depend on soil type, management practices like seedbed conditions and soil moisture, sowing depth, sowing time, fungicide dressings of seeds, presence of weeds and seasonal rainfall (Matthews et al., 2001).

Since plant density has a direct effect on the cost of seed and final yield, information on this line is highly vital when a new variety is released and growing environments are changed. Optimum plant density of a crop variety at one location may not apply at other locations because of variation in soil type and other environmental conditions; there is a need to develop site-specific recommendations (Gezahegn *et al.*2016).

Shalaby and Mohamed (1978 a) found a significant increase in the number of branches to plant at the distance 25 cm when a single crops are planted at 25, 20, 15 and 10 cm between plants. Shalaby and Mohamed (1978b) found there was a significant increase in the total number of seeds when the distance is reduced between plants. The studies on the effect of plant population or plant density on yield and yield components of Faba bean have been carried out by many workers throughout the world. Mekkei (2014) reported that 15 cm between hills significantly produced the highest seed yield, while the 25 cm intra-row spacing gave the lowest.

Comarovschi (1979) from Romania grew the crop at plant densities of 20, 40, 60 and 80 plants per m² in row 20, 30, 40, 50, 60 and 70cm apart. The highest grain yield of 2.19 tons/ha was obtained from the 40 plants per m² in rows 40 cm apart.

In Tambolo, Italy, Bonari and Macchia (1975) tested the cultivar (minor-portrum) at plant densities of 20, 40, 60, 80 and 100 plants per m² in row 25, 50 and 75 cm apart. They found that grain yield increase with increasing plant densities up to 80 plant per m² with the best spacing between rows being at 25cm. Day (1979) found no significant difference in grain yield between 18 and 98 plants per meter square working with Faba bean cultivar minor. Keller and Burkhard (1983) in Zurich, Swize-land reported that grain yield of Faba bean increased with increasing plant populations from 10 to 80 plant per m², but stalk and seed weight per plant and harvest index were decreased.

Yucel (2013) stated that the highest seed yield of Faba bean was attained between 10 and 12 cm intra-row spacing were found to be optimum under Mediterranean condition. Shalaby and Mohamed (1981) in Egypt found that when Faba bean cultivar (Giza 2) was sown at the spacing of 10, 15 and 25cm between hills, with 1, 2 or 3 plants per hole. The grain yield decreased when spacing was increased and fewer plants per hill were left and he also stated that grain yield decreased with increasing plant population.

In Newzeland, Newton (1983) found that increased plant population from 20 to 65 plant per m² reduced the number of pod per node but had little effect on seed number per pod and weight of individual seeds. Bakry *et al.* (2011) and Khalil *et al.* (2010) reported that pod number decreased with increasing plant density. Osman *et al.* (2010) reported that 15 and 20 cm intra-row spacing gave the highest seed number, however the lowest seed number was obtained by 5cm.

Turk and Tawaha (2002) stated that plant density was negatively related to seed number of Faba bean. Plant population had a significant effect on 100-seed weight. The heaviest seeds were obtained by 15 and 20 cm intra- row spacing (Osman *et al.*, 2010).

Khalil *et al.*, (2011) reported that low plant density produced heavier grains compared with high density. Ageeb (1977a) reported that the variation in row spacing (60, 40 and 20cm), plant spacing (20, 10 and 5cm) and number of plants per hole (1 or 2) had no significant

effect on yield of the H72 cultivar grown at Hudeiba Research Station for two consecutive seasons.

Ageeb (1980) found that decreasing the plant spacing from 20 to 10cm and increasing the number of plants per hole from one to two or three, significantly increased the grain yield of Faba bean at Gezira Research Station. Ageeb ,et al (1984), reported that seed yield of Faba bean increased as row spacing was decreased from 60 to 20cm, but the difference between 20 and 40cm spacing was not significant.

Abdalla and Ibrahim (2006) working with Faba bean showed that plant spacing had significant effect on grain yield, number of pods per plant and seed weight. However, plant height was not affected by spacing up to 15cm.

2.6. Losses and Damage Caused by Weeds in Faba Bean

Weeds are a permanent constraint to crop productivity in agriculture and compete for nutrients, space, and light and exert lot of harmful effects by reducing the quality as well as quantity of the crop, if the weed populations are left uncontrolled (Kavalinuskaitė and Bobinas, 2006).

Inadequate and untimely weed control operation is one of the crucial factors causing low yields of faba bean. Fessehaie (1994) reported that faba bean suffered significant yield loss of about 24% due to weed competition. The crop is highly sensitive to weed competition from the early establishment to early flowering stage and it requires weed control during this critical period. Weeds play an important role in the proper stand establishment of the growing crop, which ultimately affect the productivity and quality at the end of the growing season.

Some methods to control weeds under low input systems include intercropping and crop rotation, use of competitive crop genotypes, mechanical and hand weeding, use of appropriate sowing date and, often, optimum sowing rates.

Several crops show genotypic differences in their competitive ability mostly related to plant architecture, leaf area, leaf angle, plant stature, seed and seedling vigor. Also different weed species have different competitive abilities with crops. 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.

Bahn and Kukula (1987) reported that weeds cause considerable loss in yield of chickpea, although weeding by hand to 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. In Sudan results indicated that weed competition reduced seed yield of chickpea 80% (Mohamed et al., 1992). Also studies showed that unrestricted weed growth and delayed weeding accounted for up to 80% loss in lentil grain yield (Mohamed and Nourai, 1994).

According to Fageiry (1987) seed yield of soybean was reduced by 78-100% due to weed infestation and delay in first hand weeding beyond 30 days after sowing adversely affected the soybean yield and three hand-weeding at intervals of 15 days were necessary for adequate weed control and high yield.

Mohamed and Mohamed (1992) reported that unrestricted weed growth reduced grain and straw yield of faba bean by 64% and 70% respectively. When weeds are left uncontrolled they caused serious loss on grain yield of faba bean amounting to 70% (Babiker and Khalid, 1990).

Faba bean is poor competitor to weeds particularly in the seedling stage. This makes integrated weed control essential for successful crop production. The primary tillage should be done several weeks before planting and kill emerged weed with shallow tillage just ahead of planting consider rotary hoeing the field 7 to 10 days after planting and use spacing cultivator, if holes between 20 or 10cm (Oplinger et al. 1989).

Weed growth reduce Faba bean seed yield by 24% (Kavurmaci et al, 2010). He reported that weed had significant effect on Faba bean yield and yield components, he concluded that plots free of weeds gave the tallest plants from which the highest yield was obtained. Ageeb (1977) reported that weed effect on grain yield of Faba bean was not significant. Stagnari and Pisante (2011) stated that with an increased cycle length of weed presence in the farm a decreasing trend in the pod number and bean performance.

Kavurmaci et al., (2010) reported that the increased weed competition had reduced the plant height. The effect of weed elimination on the weight of 100 seeds was highly significant and the highest weight of the 100 seeds was related to the complete weeding and the lowest weight was obtained to the weeding till budding stage. Golipour et al., (2010) investigating weed control in sunflower reported that reduced seed weight was due to the competition with weeds. Van Akar et al.(1993) reported that pod number per plant as one of the most important and most sensitive components of the seed. Ghamari and Ahmadvand (2013) found that the highest seed yield was obtained in the complete weed control and the lowest was gained when weeding prior to budding treatment. The reduction in yield can be related as an unfavorable effect of weeds on the crop via reduction of growth resources which with reduction of yield components lead to final seed reduction.

2.7. The Critical Period of Weed Control in Faba Bean

Crops are most susceptible to weed competition in the first third of their total life span. The “critical period” defines the time up to or after which weeds are tolerated by the crop without apparent losses through competition. The critical period indicates the period in which weeding is really necessary (Braun et al., 1991).

The concept of critical period was introduced by Nieto et al. (1968). It has been used to determine the period when control operations should be carried out to minimize yield losses for many crops. For most crops it is not necessary to control weeds in the first few weeks after crop and weed emergence (Zimdahl, 1988).

A field experiment was carried out in 1974 to determine the critical period in faba bean, the critical period of weed competition occurred from the 3rd to the 5th week after 50% crop emergence and when weeds were not controlled seed yield was reduced by 46% (Glasgow et al., 1976).

Weeds can cause substantial losses to faba bean production when they are not removed during critical period of competition. The critical period of weed competition varies from 3 to 8 weeks after crop emergence. In general, faba bean is more sensitive than field pea to weed competition. The numerous weeds affecting these crops are from broad leaves and both annual and perennial grasses. Major weeds in faba bean crops are managed with hand weeding or by spraying herbicides. Two times hand weeding is very essential for faba bean one 3-4 weeks after emergence and the second 6-8 weeks after emergence.(EIAR, 2018)

2.8. Integrated weed management in Faba bean

Low-input, sustainable agriculture addresses multiple objectives from increasing profits to maintaining the environment, and builds on multiple systems as integrated pest management (IPM), integrated weed management (IWM), and crop rotation. Integrated weed management involves the combination of a number of weed control practices that reduces the dependence on any one type of control method and also lowers the input of herbicides. This approach is important for the control of perennial weeds that are inadequately controlled by any single method (Bridgemohan et al, 1991).

The application of IWM also includes the knowledge of past annual and perennial weed populations in fields and weed seed bank (Bridgemohan and Brathwaite ,1988) competitive crop cultivars, improved crop and soil management practices, and appropriate selection of herbicides (Schweizer, 1988).

Integrated weed management in legumes has been increasing interest in sustainable weed management in low-input farming system. Physical, cultural and agronomic weed control are usually less effective compared with chemical control ,but from an integrated point of view the application of several management practices may represent a practicable way to reduce herbicides rates (Anderson, 2007). In order to control weeds, cultural strategies can largely

be put into practice by choosing competitive species and manipulating plant density and plant spacing.

On grain legumes, studies have mostly focused on plant density as an important factor affecting weed competition, and consequently grain yield while less information is available on plant lodging. Spatial arrangement in grain legumes may reduce weed emergence and increase crop competitive ability; indeed, narrow rows generally increase plant height, which is positively correlated with a powerful weed suppression capability (Mohler, 1996). These effects cannot be generalized, since they are dependent up on crop species and location .Plant competition in grain legumes suggests that the ability of crops to suppress weeds at high crop density is often inversely correlated with grain productivity (Benvenuti and Macchia,2000), because of intra-crop competition.

Herbicide use continues to be one of the most important tools in weed management. However, an IWM approach creates an opportunity to reduce herbicide rates and in some instances, just forgo the use of herbicides altogether. Given the high cost of herbicides in the tropics, smallholders sometimes either reduce the herbicide rate or mix with other herbicides with differing modes of action. These practices are not without risk. Oftentimes, smallholders realize that these practices are inconsequential and there is no recourse with pesticide retail outlets regarding poor herbicide performance if label rates have not been followed. Yet, farmers often cut rates as a cost saving strategy.

The effectiveness of a reduced rate usually depends on the type of herbicide, weed species present, weed pressure, environmental conditions and, of course, the competitiveness of the crop stand. If the weed pressure is high or the weeds are under stress, it is probably advisable to use an integrated approach. However, reduced rates of herbicide may lead to some level of herbicide resistance and thus the approach to be taken must be carefully considered.

The extent of herbicide use in the tropics is closely related to the cost and availability of labor. Large scale rice and banana production in the tropics receive more than two herbicide applications. However, in the smaller farms, only about 50% of the rice area is treated, particularly where rural labor is available. Herbicides replace hand weeding and enable direct seeding which is less labor demanding, compared to transplanting. Herbicides are also used in the transplanted systems, though to a much lesser extent, and in systems particularly where crop

rotation is practiced. There is a need to reduce herbicide input in crop production which can complement cultural practices. With proper timing and selected application methods, good control may be achieved with one-fourth to one-half rates of application (Bridgemohan and Brathwaite ,1988)

Integrated weed management (IWM) systems approaches in the tropics includes any or a combination of the following practices that give a crop a comparative advantage in competing with weeds. (Mashingaidze and Chivinge, 1995). These includes:

Prevention strategies include field sanitation and harvesting methods that do not spread weed seeds and vegetative prop gules at every step of production (such as seed selection, field preparation, planting, fertilization, irrigation, weed control, harvest and transport).

Competitive crops differ in their competitiveness with weeds based on their emergence, leaf-area expansion, light interception, canopy architecture, leaf-angle, shape and competitiveness. Within a crop species, cultivars may vary in their competitiveness. While the improved varieties may be high yielding, the traditional varieties exhibit multiple adaptations, competitive ability against weeds and require less agricultural input. The use of competitive crops to discourage weeds is an important IWM strategy.

Optimum plant population like Row spacing and seeding rate may influence the ability of the crop to compete with weeds for resources and, therefore, may affect weed management (Donovan et al 2001).

Cover crops have long been used extensively in the tropics for soil and water conservation, to maintain soil structure and enhance soil fertility, especially on steep or difficult terrain. They are often referred to as living mulches. The use of leguminous cover plants to suppress weeds in plantation crops in the tropical world dates back many decades, but the integration of the legumes into arable cropping systems has not been developed to a level acceptable to farmers. Cover crops also contribute to pest management and help to suppress unwanted weeds. Its use has been mainly in plantation crops. The introduction of inexpensive nitrogen fertilizers and herbicides encouraged many farmers to discontinue this practice. Cover crops can be intercropped or interplanted with a crop of economic significance. They work by

excluding light and limiting weed emergence. Examples of cover crops in the tropics include: *Desmodiumheterocarponvarovalifolium* .

All crop husbandry practices, particularly precision placement and timing of fertilizer application, enhance maximum stimulation of the crop and minimum stimulation of the weed population. Additionally, the use of clean certified seeds, clean farm implements, effective seedbed preparation and seeding methods that improve crop growth, all reduce weed competition (Bridgemohanand Brathwaite, 1988)

Irrigation practices such as the use of clean water, channels and canals, can reduce the spread of weed seeds to uninfected fields.

Inter-row cultivation and minimum tillage refers to inter-row cultivation is practical in widely spaced row crops, such as maize, vegetables, sugarcane and banana.

Intercropping or relay cropping systems are based on the principle that space should be occupied by crops and not weeds. Relay cropping can be practiced by market gardeners who harvest their crops by hand. These crops should be planted in such a way that the intercrop provides an effective canopy to shade weeds, or that previous crop residue can be used as a mulch to prevent weed growth in succession crops, e.g., pigeon pea (*Cajanuscajan*) interplanted with maize (*Zea mays*).

The use of biological agents such as mycoherbicides, insects and pathogens to control weeds in the tropics is not common. However, the potential for its application to control noxious weeds using monophagous/ oligophagous natural enemies must not be overlooked (Labrada,R,2005)

A mix of adoption strategies has been used over the years in an effort to get the right approach to IWM. No silver bullet has been found. It is a work in progress. Given the diverse weed flora, farming experiences and farmer circumstances in the tropical world, scientists, educators and farmers will have to dedicate increased energies towards finding an approach that is economical, culturally acceptable and environment friendly.

2.9. The Use of Herbicides in Faba Bean

The major problem facing the production of faba bean in Northern Sudan is weeds, because of the low competitive ability of faba bean during the early stages of its growth (Mohamed, 1995). Weed control in faba bean in northern Sudan involve late hand weeding to collect fodder for animals, this late removal of weeds does not mitigate the adverse effect of weeds on yield. However, early hand weeding is difficult and expensive, as labor is becoming scarce. Herbicides are, therefore, of great potential importance to eliminate the early competition in faba bean (Mohamed, 1995).

According to Zahran (1983) post-sowing weedicide at 2.5 and 3.0 kg/ha and it was found as effective as hoeing twice and weed free treatments, both from the view point of its effect against weeds and its effect on crop yield. In Sudan removal of weeds was done with pre-emergence herbicides. Trial was carried out at Hudeiba to access the effect of PPOO-9 as post-emergence herbicide on annual grass weeds and its selectivity to faba bean. The herbicide was applied as aqueous spray 5 weeks after planting at 5 rates.

The overall weed control by PPOO-9 was moderate; this was attributed to the domination of broadleaf weeds and *Cyperusrotundus* which were not controlled by such chemicals. Growth inhibition or phytotoxic symptoms was not observed. The grain yields for treatments were not significantly different.

The application of 1.19 kg a.i. ha⁻¹ PPOO 9 brought 40% increase in yield over the weedy check (Badawi, 1983). Unrestricted weed growth in this crop significantly reduced plant stand, plant height and reduced number of pods/plant while there was no effect on seeds/pod or 100 seeds weight.

Mohamed et al., (1998) reported that herbicides goal at (0.2, 0.4, 0.6) L/ha, Ronstar at (0.5, 1, 2.0) L/ha and stomp at (1.5, 2.0, 3.0) L/ha were used to evaluate their efficacy of weed control and to see the tolerance of faba bean. Results showed that the three herbicides at their high rates used gave seed yield which was comparable to the hand weeding control and gave excellent and persistent control of annual grasses but they were less effective on annual broad leaved weeds. Field trials with faba bean showed that application of 2- 4-DB (15 ppm) one

month after sowing either alone or in combination with $\text{Fe}^{+++}\text{Mn}^{++}$ at 1500 ppm increased the yield by greater than 20% and pod number by 30% over and above the control.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted on farmer's field in Jimma zone, Omo Nada District, Chalalaka Donga kebel. The site is located at $7^{\circ}35' 17.1''$ N latitude and $37^{\circ}17' 48.5''$ E longitude and at an altitude of 2394 meters above sea level. It is situated in the tepid to cool humid-mid highlands of southwestern Ethiopia. The soil is clay in texture and moderately acidic with pH of 5.48. The organic matter content of the soil was 1.83% and with moderate total nitrogen (0.113%) and available P (8.74 mg kg^{-1}). The rainfall in the area is characterized by bimodal distribution pattern and the main rainy season (Meher) is between June and end of September and the small rain (Belg) is from late February to late March/early April. The amount of annual rainfall during the crop season was 1276 mm with a maximum and

minimum temperature of 26 and 10.60^oC, respectively (Appendix 2). The experiment was conducted during 2018 main cropping season under rain fed condition from June to November.

3.2. Soil sampling and analysis

Composite soil samples were collected from the experimental plots in a diagonal pattern from the depth of 0-20 cm before planting. Uniform slices and volumes of soil were obtained in each sub sample by the vertical insertion of an auger after which the sub-samples were made into a composite sample. Then, the composite soil sample was dried, ground using a pestle and a mortar and allowed to pass through a 2-mm sieve and analyzed for the selected soil physicochemical properties mainly organic carbon, total nitrogen, soil pH, available phosphorus, cation exchange capacity, and textural analysis using standard laboratory procedures. Soil sample was analyzed following standard laboratory procedures as outlined by (Sahlemedhin and Taye, 2000). The soil analysis was carried out at Jimma Agricultural Research Center Soil and Plant Tissue Analysis Laboratory.

The textural composition of the experimental soil is 27.8% sand, 27.6% silt and 44.6% clay (Table 1) and categorized under a textural class of clay. Soil texture is an important soil physical characteristic as it determines water intake rate (infiltration), water holding capacity in the soil, the ease of tilling, the amount of aeration and also influence soil fertility (Gupta, 2000). It has also been reported that, for best production of the crop, faba bean should be grown on well-structured loam or clay soils with pH of 6.5 to 9.0 (Jensen *et al.*, 2010).

The soil reaction of the experimental site (pH = 5.48) was moderately acidic (Table 1) as per the ratings of Tekalign (1991). Soil pH is an important factor for plant growth, as it affects nutrient availability, nutrient toxicity, and has a direct effect on the protoplasm of plant root cells (Alam *et al.*, 1999).

The organic carbon content of the soils was 1.83% (Table 1) which is rated as moderate (Tekalign, 1991). The lower organic matter (OM) content in cultivated land soil is attributed to anthropogenic factors like reduced crop residues or biomasses return to the soil as a result of removal of plant and animal organic sources and livestock grazing.

The total nitrogen of the experimental soil was 0.133% which is in ranges of moderate (Table 1) as per Tekalign (1991) rating. The available P of the experimental soil was 8.74ppm (Table 1) which is moderate as per the rating of Bray and Kurz (1945). According to Tisdale et al.(2002) plants' demand to available P vary where low demanding crops require concentration of P > 8ppm, moderate-demanding crops > 14ppm and high demanding crops > 21ppm. Acidic soils are naturally deficient in available P and significant portions of applied P are immobilized due to precipitation of P as insoluble Al phosphates. However, the soil acidity correcting agents such as the use of liming materials could reverse this situation and increase soil P to adequate levels. The high reactivity of P with iron, aluminum and calcium, to form insoluble compounds, reduces its mobility in the soil solution (Boudanga et al., 2015).

The cation exchange capacity of the experimental soil was moderate 21.55cmol⁽⁺⁾ kg⁻¹ (Table 1) according to Landon (1991) rating. Organic matter particularly plays important role in exchange process because it provides more negatively charged surfaces than clay particles do (Johnson, 2002).

Table 1 Soil physico-chemical properties of the experimental site before planting at Omo Nada in 2018

Soil Parameters	Value	Rating	Reference
P ^H (1: 2.5 H ₂ O)	5.48	Moderately acid	Tekalign (1991)
Av. P (ppm/kg soil)	8.74	Medium	Bray and Kurtz (1945)
CEC (cmol(+) kg ⁻¹)soil	21.55	Medium	Landon (1991)
Organic Carbon (%)	1.83	Medium/moderate	Tekalign (1991)
Total Nitrogen (%)	0.133	Medium/moderate	Tekalign(1991)and BerhanuDebele (1980)
Sand (%)	27.8		FAO(1990)
Silt (%)	27.6		
Clay (%)	44.6		
Textural Class	Clay		

Where pH= hydrogen power, OC=organic carbon, TN=Total Nitrogen, Av.P=Available phosphorous and CEC=Cation exchange capacity.

3.3. Treatments and Experimental Design

The experiment was conducted with four levels of inter rows spacing (30cm, 40cm, 50cm and 60cm) and five levels of weeding practices (Unweeded. once hand weeding 20 days after emergency(DAE), twice hand weeding at 20 and 40 DAE, three times hand weeding at 20, 40, 60DAE and Pre-emergence herbicide (Dual Golden 960 EC) application at the recommended rate (1.0kg ha⁻¹)which was supplemented with one time hand weeding at 40DAE. The spacing between plants or within rows was the same, i.e.10cm for all the experimental units (Table 2).

Faba bean genotype named Tumsa was used for the study. It was released by Holeta Agricultural Research Centre in 2010. It performs well in agro-ecology of 1800-3000 m.a.s.l with rainfall of 700-1000 mm and well adopted by farmers.Faba bean variety *Tumsacan* produce 2.5-5.0 and 2.1-3.5 t ha⁻¹ grain yields under on-station and on-farm conditions, respectively. It was characterized by indeterminate growth habit with 120-130 days to maturity andmoderately resistant to chocolate spot. Thetreatment combinations were arranged in Randomized Complete Block Design (RCBD) in 4 x 5 factorial arrangement with three replications (Table 2).

The gross plot size and net harvest area were 2.5m width x 6 m length (15 m²) and 1.8m x2.5m (4.5m²), respectively. Therewere20,15,12 and 10rowsperplotunder30, 40, 50and60 cm inter row spacings,respectively.The harvested number of rows or row length in meter (in parenthesis) were6 of 20 rows (15m), 4.5 of 15rows (11.25m),3.6 of 12 rows (9m)and 3 of 10 rows (7.5m)for inter row spacings of 30,40, 50and60cm ,respectively.

Table 2. Details of treatments Combinations of inter row spacings and weed management

Treatments No.	Inter Row spacing levels*weedmanagement	Treatment description
1	S ₀ W ₀	30cm inter row spacing and un weeded plot
2	S ₀ W ₁	30cm inter row spacing and one time weeding at 20 DAE
3	S ₀ W ₂	30cm inter row spacing and twice hand weeding at 20 and 40 DAE

4	S ₀ W ₃	30cm inter row spacing and three times hand weeding at 20,40 and 60 DAE
5	S ₀ W ₄	30cm inter row spacing and S-metolachlor 1.0 kg ha ⁻¹ or Dual Golden 960EC pre-emergence herbicide supplemented by one hand weeding at 40DAE
6	S ₁ W ₀	40cm inter row spacing and un weeded plot
7	S ₁ W ₁	40cm inter row spacing and one time weeding at 20 DAE
8	S ₁ W ₂	40cm inter row spacing and twice hand weeding at 20 and 40 DAE (control)
9	S ₁ W ₃	40cm inter row spacing and three times hand weeding at 20,40 and 60 DAE
10	S ₁ W ₄	40cm inter row spacing and S-metolachlor 1.0 kg ha ⁻¹ or Dual Golden960EC pre-emergence herbicide supplemented by one hand weeding at 40DAE
11	S ₂ W ₀	50cm inter row spacing and un weeded plot
12	S ₂ W ₁	50cm inter row spacing and one time weeding at 20 DAE
13	S ₂ W ₂	50cm inter row spacing and twice hand weeding at 20 and 40 DAE
14	S ₂ W ₃	50cm inter row spacing and three times hand weeding at 20,40 and 60 DAE
15	S ₂ W ₄	50cm inter row spacing and S-metolachlor 1.0 kg ha ⁻¹ or Dual Golden 960EC pre-emergence herbicide supplemented by one hand weeding at 40DAE
16	S ₃ W ₀	60cm inter row spacing and un weeded plot
17	S ₃ W ₁	60cm inter row spacing and one time weeding at 20 DAE
18	S ₃ W ₂	60cm inter row spacing and twice hand weeding at 20 and 40 DAE
19	S ₃ W ₃	60cm inter row spacing and three times hand weeding at 20,40 and 60 DAE
20	S ₃ W ₄	60cm inter row spacing and S-metolachlor 1.0 kg ha ⁻¹ or Dual Golden 960EC pre-emergence herbicide supplemented by one hand weeding at 40DAE

Where;S₀=30cm,S₁=40cm,S₂=50cm,S₃=60cm and W₀:Non Weeding; W₁;Hand weeding using hoe onetime at 20DAE; W₂;Hand weeding using hoe two times at 20DAE and 40 DAE; W₃; Hand weeding using hoe three times at 20, 40 and 60 DAE;W₄:Dual Gold herbicide supplemented by hand weeding at 40DAE;DAE=Days after emergency

3.4.Experimental Procedures and Crop Management

The field was well prepared by plowing three times. Faba bean was hand planted on the 14 July 2018 on a plot size of 6mx2.50m (15m²). Two seeds were placed per hill to ensure the desired stand in each treatment and thinning was practiced after 10 DAE to one plant/hill as of the intended treatments. The planting space was varied between rows at 30cm, 40cm,50cm and 60cm distance but the same 10cm was used within rows ,i.e.30cm*10cm (333,333),

40*10cm (250,000), 50cm*10cm (200,000) and 60cm*10 cm (166,667plants ha⁻¹).In accordance with specifications of the design, each treatment was assigned randomly to the experimental units within a block.

Blended NPS fertilizer (19N–38P2O5-0K-7S grade) was applied at a rate of 100kgha⁻¹ in the rows at the time of planting. Pre-emergence herbicideDual Gold 960 EC (trade name), S-metolachlor (Common name), and [2-chloro-6-ethyl N-(2-methoxy-1-methylethyl) acet-o-toluidide (chemical name) was applied to the respective experimental unit before planting as per the recommendation, i.e.1.0 kg ha⁻¹.

Hand weeding practices were doneusing hoe as specifiedfor eachexperimental unit except for the non-weeded plot. Harvesting and threshing were done by hand. All the necessary agronomic practices and crop management activities were undertaken as recommended for faba bean.

3.5. Data Collection

3.5.1. Weed Parameters

Important weeds of the crop were assessed and recorded. The data on Weed species was collected from each unit plot three times at 20, 40 and 60 DAE. A square quadrat of 0.5m x0.5m was placed at three different spots per plot .The infesting species of weeds within the quadrat was identifiedby using colored picture manuals and with the aid of flora books (Stroud and

Parker, 1989; Melaku, 2008; Naidu, 2012) and plant net application system.

The population of broadleaved, grass and sedges in a plot size of 0.5m x 0.5m was counted. Summation of individual plants of each weed species in quadrats divided by the number of quadrats multiplied to area of quadrat was used for weed density m^{-2} calculation per experimental unit. The above ground harvested weeds were tagged and placed into bags separately and air dried before drying in oven at $65^{\circ}C$ temperature till constant weight obtained which means subsequently the dry weight was measured. Weed data on the following parameters were collected.

3.5.1.1. Weed species

The infesting weed species within the quadrat was identified by using colored picture manuals and with the aid of flora books (Stroud and Parker, 1989; Melaku, 2008; Naidu, 2012) and plant net application system. The category wise (broadleaved, grass and sedges) population count was taken from plot size of 0.5m x 0.5m.

3.5.1.2. Weed dry biomass

While recording weed density, the harvested above ground weed from each quadrat was placed into p bags separately and air dried for 3-4 days. After air dried for 3-4 days, the harvested weed were placed in oven at $65^{\circ}C$ for 24 hours till constant weight obtained. Subsequently, the dry weight was measured and then converted in to $g m^{-2}$

3.5.1.3. Relative weed density

The relative weed density of each species was calculated using the following formula (Fadayomi and Takim, 2009)

$$RWD = \frac{NIW}{NTW} \times 100$$

Where: RWD- Relative weed density, NIW- Number of plants of individual weed species in quadrat, NTW- Number of plants of all weed species in quadrat.

3.5.2. Crop data

3.5.2.1. Phenological parameters

3.5.2.1.1. Days to flowering (DF)

Days to flower was determined by counting the number of days from the date of sowing to the period when 50% of the plants produce flower.

3.5.2.1.2. Days to Physiological maturity (DM)

Days to Physiological maturity was recorded as the number of days from sowing to the time when about 90% of the plants have mature pods in their upper parts with pods in the lower parts of the plants turning dark.

3.5.2.2. Growth parameters

3.5.2.2.1. Leaf area (LA)

Leaf area was calculated by leaf area estimation model as described by Peksen(2007) and three leaves per plant were measured and the mean values was multiplied by the total number of leaves per plant and averaged over ten selected plants at pod initiation.

$$LA = 0.919 + 0.682LW$$

Where LA (cm²) = leaf area L= leaf length(cm) and W = leaf width (cm)

3.5.2.2.2. Leaf area index (LAI)

Leaf area index at pod initiation was computed. It is a measure of leafiness per unit ground area and denotes the extent of photosynthesis (Peksen.2007).It was calculated by the formula

$$\text{LAI} = \frac{(\text{Leaf Area} * \text{Number of leaf per plant})}{\text{area covered by plant}}$$

3.5.2.2.3.Plant height (PH)

Plant height was the average height (measured from base to top bud) and the average value of ten randomly selected plants from each plot was taken at physiological maturity.

3.5.2.2.4. First pod setting height (FPH)

First pod setting height was measured by taking average height from base to the first productive pod of ten randomly selected plants for each plot at physiological maturity.

3.5.3. Yield and Yield Components

3.5.3.1. Number of productive tillers per plant(NPTPP)

Number of productive tillers was determined at maturity by counting all tillers /branches producing/setting pods of ten randomly selected plants from each plot and the values was averaged per plant.

3.5.3.2. Number of pods per plant (NPPP)

Number of pods per plant was the average numbers of pods counted from samples of ten randomly selected plants from each plot.

3.5.3.3. Number of seeds per pod (NSPP)

It was the total number of seeds per plant divided by the total number of pods on the same plant and averaged over ten plants randomly selected from central rows of each plot.

3.5.3.4. Dry biomass (BM)

All above ground plant part per net harvest area in each plot was harvested at maturity, threshed and measured after well sun dried for uniform weight and converted into kg per hectare.

3.5.3.5. Harvest index (HI)

Manfred (1993) and Rkmhay (1995) defined harvest index as the ratio of grain yield to above ground biomass of net plot. Hence, it was calculated as

$$HI(\%) = \frac{YD}{BM} * 100$$

Where HI=harvest Index, YD=Grain Yield and BM=above ground biomass

3.5.3.6. Grain yield (YD)

The weight of seeds obtained from net harvested area of each plot was measured using electronic sensitive balance after adjusting to 11.5% moisture content and computed for its mean values, then converted to yield in kg per hectare.

3.5.3.7. Thousand Seed weight (TSW)

Thousand seeds were randomly taken from bulk of threshed seeds in each plot and after adjusting to 11.5% moisture content, their weight was measured for mean values per plot.

3.6. Partial Budget Analysis

To investigate the economic feasibility of the treatments partial budget analysis was conducted. The average yield was adjusted downwards by 10% to reflect the difference between the experimental yield and the expected yield of farmers from the same treatment. This is done because experimental yields, even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments (CIMMYT, 1988).

The amount of seed required was varied with inter row spacing and also the number of labours required was varied with weeding regime and so do herbicide used. However, other input costs like fertilizer used considered to be constant for all treatments.

A dominance analysis was carried out by first listing the treatments in order of increasing costs that vary. Any treatment with net benefits less than or equal to those of treatments with lower costs is dominated and not used for further MRR analyses.

The process of calculating the marginal rates of return (MRR) of alternative treatments, proceeding in steps from the least costly, and deciding if they are acceptable to farmers, is called marginal analysis. According to CIMMYT (1988), the tentative recommendations was computed based on the comparisons of the rates of return between treatments and the minimum rate of return acceptable to farmers i.e. 100%. Consequently, any treatment with MRR of greater than 100% is considered as a profitable treatment and recommended to be used by farmers. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time of harvest. All costs and benefits were calculated in Ethiopia Birr (ETB) per hectare.

Partial budget analysis was conducted based on the following concepts: These includes mean grain yield is the average yield (kg ha^{-1}) of each treatment. The field price of faba bean grain

is its point of sale at retail price minus the costs of harvesting, bagging and transporting .The gross field benefit (GFB) ha⁻¹ is the product of field price of faba bean grain and the mean yield for each treatment. The field price of seed kg⁻¹ is the seed retail cost kg⁻¹ plus the cost of transport from the point of sale to the farm .The field cost ha⁻¹ seed is the product of the quantity required by each treatment per hectare and the field price of seed. The field cost of Dual Gold 960 EC herbicide is the chemical retail cost Liter⁻¹ plus the cost of transport from the point of sale to the farm.The cost of Labor for weeding is the product of man-days used in weeding and wage rate. The total variable costs (TVC) is the sum of field cost of seed and Laborfor weeding and herbicide cost. The net benefit (NB) ha⁻¹ for each treatment is the difference between the GFB and the TVC.

Therefore, to select potentially profitable treatments from the range was tested. A percentage of marginal rate of return (MRR) was calculated.

$$\text{MRR (between treatments, a and b)} = \frac{\text{change in NB (NBb-NBa)}}{\text{change in TVC (TVCb-TVCa)}} \times 100$$

Where, NBb=net benefit from treatment b;

NBa=Net benefit from treatment a

TVCb=Total variable cost of treatment b;

TVCa= Total variable cost of treatment a

3.7. Data Analysis

The data were subjected to Analysis of variance (ANOVA) using SAS software version 9.3. Least significant difference (LSD) at 5% level of significance was used to separate treatment means. Weed density data was transformed by using a square root transformation to harmonize the data set. Correlation analysis were performed to determine the association among variables.

The analytical Model for the experiment was:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + r_k + (\alpha\beta)_{ij} + e_{ijk}$$

Where:

- μ = the overall mean effects

- α_i = the effect of i^{th} level of inter row spacing level $i=1-4$
- β_j = the effect of j^{th} level of weeding level $j=1-5$
- r_k =the effect of k^{th} replication
- $(\alpha\beta)_{ij}$ =the interaction effect of inter row spacing and weeding level
- e_{ijk} =the random error compared for the whole factor
- k =number of replications

4.RESULTS AND DISCUSSIONS

4.1. Effects of Inter Row Spacing and Weed Management on Weed Parameters

4.1.1 Weed Species composition

Nine families and fifteen weed species comprising eleven broadleaved, three grasses and one sedge were identified in weedy plots at 60DAE. The species identified includes: *Galinsoga parviflora* Cav. *Polygonum nepalense*, *Guizotia scabra* (Vis.) Chiov, *Bidens pachyloma*, *Bidens pilosa*, *Medicago polymorpha*, *Galium aparine*, *Amaranthus spinosus*, *Rumex crispus*, *Datura stamonium*, *Portulacaoleracea*

L. Setariaviridis(L) Beauv, *Cynodonnlemfuensis*,*Snowdenia polystachya* and *Cyperusrotundus* L. Among these species *Galinsoga parviflora* Cav. was observed with the highest relative weed density followed *Polygonumnepalense*. *Cyperusrotundus* L was lowest in relative weed density. Weed infestation relative density by Broad leaves, Grass and sedge were 73.63%, 21.70% and 4.67% respectively (Table 3).

The result was in agreement with the findings of Rezene *et al.* (1992) and Kasaet *et al.* (2002) who reported that among the annual weeds *Cyperusrotundus* of the family *Cyperaceae* are disastrous and *Galinsoga parviflora* Cav, *Guizotiascabra*, and other broadleaf and grass weeds are important in southwestern parts of the country.

The possible reason for more weed species occurrence in the field could be related to high weed seed in soil bank and favorable environmental factors such as soil type, altitude, and previous crop grown in the site and more rainfall at early stage of the crop growth. In line with this result, Tamado and Milberg (2000) reported that altitude, rainfall, month of planting, number of weeding and soil type were the major environmental and crop management factors that influenced the number of weed species.

Table 3 Weeds species composition and mean relative density of non-weeded plots in 2018.

Botanical name	Family	Relative density (%)
Broad leaf		73.63
<i>Galinsoga parviflora</i> Cav	Astraceae	11.45
<i>Polygonumnepalense</i>	Polygonaceae	10.38
<i>Guizotiascabra</i> (Vis.) Chiov	Asteraceae	10.17
<i>Bidens pachyloma</i>	Astraceae	10.10
<i>Medicagopolymorpha</i>	Fabaceae	8.89
<i>Galiumaparine</i>	Rubiaceae	5.78
<i>Rumexcrispus</i>	Polygonaceae	4.04
<i>Bidenspilosa</i>	Asteraceae	3.77
<i>Amaranthusspinosus</i>	Amaranthecea	3.36
<i>Datura stamonium</i> L	Solanaceae	3.32

<i>Portulacaoleracea</i> L	Portulacaceae	2.37
Grass		21.70
<i>Snowdonia polystachya</i>	Poaceae	10.20
<i>Cynodonlemfuensis</i>	Poaceae	5.42
<i>Setariaviridis</i> (L) <i>Beauv</i>	Poaceae	6.08
Sedge		4.67
<i>Cyperusrotundus</i> L	Cyperaceae	4.67
		100.00

4.1.2. Weed density and dry weight

4.1.2.1 .Weed density

Weed density was significantly ($P < 0.05$) influenced by interaction effects of inter row spacing and weeding treatment (Appendix Table 1). At any growth stage of the crop, weed density was highest with widest inter row spacing (60cm) and non-weeding. Significantly ($P < 0.05$) the highest mean total weed densities was obtained for 60 cm inter row spacing with unweeded plots at 20, 40 and 60 DAE with mean values of 57.53, 52.65, and 55.46 weed m^{-2} , respectively. Whereas, the lowest (0.5 weed m^{-2}) weed density at 60 DAE was observed for combination of three times hand weeding and 60cm inter rows spacing which was statistically at par with combination of all inter rows spacing and three times hand weeding (Table 4).

The higher weed densities were observed for the combination of 40cm inter row spacing and unweeded plots at 20, 40 and 60 DAE with mean values of 58.57, 58.573 and 48.94 weed m^{-2} and those values were statistically at par with 50 and 60cm inter row spacing with unweeded combination.

For the first 20 DAE, all inter row spacings with herbicide treatments before emergence supplemented with hand weeding at 40 DAE gave the lowest weed density (0.5 m^{-2}) but the highest weed density at the same day observed for widest or 60cm inter row spacing plus with unweeded plot. Hence, as weeding levels increase from unweeded to one time, twice and

thrice hand weeding, weed density decrease as compared to the mean weed density values of the unwedded treatments with the same spacing over time.

The reason for highest weed density for the combination of widest inter-row spacing (60cm) and unwedded conditions could be lack of weed interruptions which might have provided adequate and more space for weeds to occupy than did the other narrower inter row spacing. Less number of weed density (0.5m^{-2}) were found from all inter row plant spacing combined with three times hand weeding at 60DAE.

Furthermore, interaction of narrowest inter row (30cm) plant spacing combined with unwedded gave the lowest weed densities as compared to the wider (50 and 60cm) inter row spacings with unwedded treatments. This could be attributed to competitive advantage of the crop; as the later emerging weeds were more suppressed by taller crop plants under closer spacing, thereby, resulting in reduced total weed density.

In line with this, Holmes and Sprague (2013) reported weed suppression was maximized in narrower (38 cm) than wider (76 cm) row spacing in common bean. In agreement with the current finding, Yohannes (1997) has also reported that faba bean required at least two early weeding (20 and 40 days after emergence) for efficient weed management, which led to significantly higher crop yields. The uninterrupted growth of weeds might have offered severe competition to the crop, thereby, interfering in the utilization of various growth factors.

Table 4 Interaction effects of inter row spacing and weed management on weed density and dry weight during 2018 main cropping at Omonada

Treatments	weed density m^{-2}			weed dry matter (gm^{-2})		
	20DAE	40DAE	60DAE	20DAE	40DAE	60DAE
S0W0	47.28bc	41.98b	35.44d	19.527c	37.66c	52.34c
S0W1	40.12de	23.02cd	14.57f	15.8d	16.63de	19.42d
S0W2	32.17fg	21.24cde	7.46h	14.567	10.703f	2.48g
S0W3	8.50h	0.5f	0.5i	3.473g	0.33g	0.23g

S0W4	0.5i	15.91de	14.57f	0.23i	11.35def	14.58ef
S1W0	58.57a	58.57a	48.94b	24.267b	53.07b	60.97b
S1W1	0.5i	19.46cde	14.57f	18.85a	15.44def	18.83de
S1W2	28.50g	12.94e	10.42gh	12.163e	11ef	4.523g
S1W3	5.81h	0.5f	0.5i	1.123i	0.33g	0.23g
S1W4	40.48cde	18.87cde	18.13e	0.23i	15.443def	4.647g
S2W0	52.49ab	52.65a	40.06c	22.35b	47.74b	55.64c
S2W1	34.14efg	17.68cde	13.98f	15.06d	16.92d	19.29d
S2W2	28.50g	25.98c	13.98f	9.76f	11.59def	4.463g
S2W3	8.05h	0.5f	0.5i	2.02gh	0.33g	0.23g
S2W4	0.5i	17.69cde	7.463h	0.23i	16.92d	1.8g
S3W0	57.53a	52.65a	55.46a	29.56a	59.59a	78.89a
S3W1	41.89dc	12.35e	11.61fg	19.40c	14.85def	18.24de
S3W2	36.04def	15.31de	9.24gh	16.523d	11ef	3.22g
S3W3	8.38h	0.5f	0.5i	3.1gh	0.33g	0.23g
S3W4	0.5i	18.28cde	9.24gh	0.23i	16.03def	10.33f
Mean	26.52	34.13	16.36	11.42	18.36	18.53
LSD (5%)	3.2632	4.32	1.57	0.9968	2.56	2.02
CV	16.64408	26.3	13.0176	11.8052	18.87	14.76

LSD = Least Significant Difference; CV = Coefficient of Variation; Means values followed by the same letter(s) within the column are not significantly different at 0.05 probability level.

4.1.2.2 Weed dry biomass (gm^{-2})

The interaction of inter row planting space and weeding regime significantly ($P < 0.05$) affects weed dry biomass (Appendix Table 1). The highest dry weight was recorded for 60cm inter row spacing with unweeded treatment at 20, 40 and 60DAE with mean values of were 29.56, 59.59 and 78.89 gm^{-2} , respectively (Table 4). The highest weed dry weight in non-weeded (78.89gm^{-2}) plot at widest inter row spacing(60cm) might be due to higher weed density(55.46 m^{-2}) that provided an opportunity to the weeds to compete vigorously for nutrients, light and water. As the number of days after crop emergence increased from 20 to 60DAE, dry weight accumulation by the weeds also increased in unweeded plots (Table 4).

The highest weed dry weight (78.89 g m^{-2}) was recorded in unweeded treatment with 60cm inter row spacing at 60DAE, which was significantly higher than the values for all inter row spacings and weed management practices.

Unweeded plots under the widest (60cm) inter row spacings gave the highest dry matter due to high number of weed density and high accumulation of dry matter. High dry matter accumulation under wider space gave advantage to weeds to use resources like sun light, nutrients, air, moisture and space in more efficient way.

This observation was in agreement with the findings of Naem et al (2000) who reported significant decrease in weed dry weight in all weed management practices showed as compared to weedy check in garden cress (*Lepidium sativum* L.) crop.

4.2. Effect of Inter Row Spacing and Weed management On Phenological parameters

4.2.1. Days to 50 % flowering

The number of days required for 50% flowering was significantly ($P < 0.05$) affected by inter row spacing (Appendix Table 1). But, it was not significantly affected by weeding regimes nor by the interaction of weeding and spacing. The lowest values (56 days) was recorded for narrow inter row spacings (30cm and 40cm). Whereas, the longest days to reach 50% flowering (58 days) was recorded from the wider inter row spacings of 50cm and 60cm (Table 5). This finding was in line with that of Shad K. et al (2011) who reported on faba

beanthin plant density or wider spacing ($150,000\text{ha}^{-1}$) of faba bean took more days to flowering (60.5) compared with thick plant density ($600,000\text{ha}^{-1}$).

The result of this study was also in agreement with the findings of Alessiet *al* (1977) who reported significantly delayed flowering of sunflower planted at wider spacing than the denser planting. Similarly, Ahmad *et al*(2002) also reported that sesame row spacing had significant effect on number of days to flower and maximum days (56) was taken to flower at 60 cm row spacing, while crop sown at 30 cm rows took minimum days (52) to flowering and this might be attributed to more nutritional area available in wider spacing, which caused more vegetative growth.

Turk *et al* (2003) have also reported that high plant density promotes phenological development; with flowering occurring 14 days earlier in the high plant density of lentil. Furthermore, Al-Rifaeet *al*(2004) have found that plants from lower densities flowered significantly later than those from higher densities.

4.2.2. Days to 90% maturity

The number of days required for 90% maturity was significantly ($P < 0.05$) influenced by inter row spacing (Table 5). But, weeding treatments or weeding by spacing interaction had no significant effect on number of days to physiological maturity. The narrow inter row spacings (30cm and 40cm) with different combinations of hand weeding resulted in minimum days to physiological maturity (135 days). Whereas, the maximum value (142.00 days) was recorded for the wider inter row spacing of 60cm and 50cm. Physiological maturity of the crop was later by 7 days at wider inter row spacings (60cm and 50cm) than narrower inter row spacing (40cm and 30cm).

This result was in agreement with that of Langham (2007) who noted that plant spacing affects the phenotype and length of time of the phases and stages as plants compete for light at high population densities and tend to mature earlier and faster than low population density. These results were also in agreement with the findings of Lopez et al. (2005) and Oad et al. (2000) who reported that closer row spacing increased number of days to maturity.

Table 5. Main effects of inter rows spacing on faba bean DF and DM during 2018 main cropping season

Inter rows Spacing	DF (50%)	DM (90%)
30cm	56b	135b
40cm	56b	135b
50cm	58a	142a
60cm	58a	142a
Mean	57	138.5
LSD(5%)	1.13	1.15
CV	1.40	1.74

LSD = Least Significant Difference; CV = Coefficient of Variation; DF=Days to flowering; DM=Days to physiological maturity. Means values followed by the same letter(s) within the column are not significantly different at 0.05 probability level.

4.3. Effects of Inter Row Spacing and Weed management on Growth

4.3.1. Leaf area index (LAI)

Leaf area index was highly significantly ($P < 0.05$) affected by the interaction of inter row spacing and weeding frequency (Appendix Table 1). Combination of the narrowest inter row spacing (30cm) and three times hand weeding gave higher LAI (2.57). The lowest LAI (0.887) was obtained from the widest inter row spacing (60cm) in non-weeded plots (Table 6).

LAI was significantly affected and inversely related to inter row spacing. Hence, the highest LAI was obtained from the narrowest inter-row spacing while the lowest was from the widest

(60cm)inter rows spacing (Table 6). This was probably due to decrease in the ground area when inter row spacing increased. This result was in agreement with López-Bellido et al. (2005) who reported that the leaf area index of faba bean was positively associated with relatively higher plant density.

Worku and Demisie (2012) have also reported that a high LAI at high plant density may attribute to improved light interception thus, ensuring high biomass and yield than at low plant density.

4.3.2. Plantheight (cm)

Inter row spacing and weed management practices as well as their interactions significantly ($P < 0.05$) influenced plant height (Appendix Table 1). The Tallest plant (176.86 cm) was obtained from narrower inter row spacing of 40 cm with one hand weeding, followed by 50cm inter row spacing (173.26 cm). The shortest plant (152.13cm) was observed for one hand weeding at 40DAE plus application of pre-emergence herbicide (Dual Gold) and the widest (60cm) inter row spacing (Table 7).

Plant height is one of the important growth parameters of any crop plant as it determines or modifies the yield contributing characters and finally shapes the grain yield. For instance, characteristics associated with high yielding modern varieties, such as short stature and erect leaves, are considered to be unfavorable for weed suppression (Johnson et al, 1998). In the current study, it was observed that plant height at physiological maturity increase from the widest inter row spacing with one hand weeding plus application of dual Gold treatment combination (152.13cm) to narrower (40cm) spacing with one time hand weeding (176.86 cm) (Table 7).

The narrowest inter row spacing gave significantly taller plants than the rest of the spacing treatments. Under narrow inter-row spacing, there is comparatively low solar radiation interception through crop canopy compared to wider inter-row spacing where there is a better light interception.

Therefore, high and low interplant competition for light in the narrow and wide spacing respectively could have resulted in such variation in plant height. These results were in agreement with the findings of Gezahegn et al. (2016) who noted taller plants in a narrow spacing because of competition for light compared to the case in wider spacing where light distribution was normal.

Dean and Mendham (2006) have also reported that plant height increased significantly with increased plant density particularly at the end of flowering. Moreover, plants grown at higher plant densities were taller than those at lower densities (Pilbeam, *et al.*1990).

Table 6. Interaction of spacing and weed management on growth parameters

Treatments	PH(cm)	FPH(cm)	LA(cm ²)	LAI
S ₀ W ₀	156.33de	93.13ab	17.75h	1.76def
S ₀ W ₁	169abcd	96.07a	24.63defg	2.42a
S ₀ W ₂	170.93ab	82.8abcd	24efg	2.3ab
S ₀ W ₃	157.13cde	90.13abc	26.42bcdefg	2.57a
S ₀ W ₄	168.8abcd	81.73abcd	24.89bcdefg	2.39ab
S ₁ W ₀	168.6abcd	83.33abcd	23.39efgh	1.65efg
S ₁ W ₁	176.87a	82.13abcd	27.76bcde	2.01cd

S ₁ W ₂	171.87ab	85.4abcd	23.58efgh	1.68efg
S ₁ W ₃	166.33abcd	78.867abcd	30.33bcd	2.13bc
S ₁ W ₄	162.27bcde	78.4abcd	26.43bcdefg	1.89cde
S ₂ W ₀	163.6abcde	83.6abcd	28.42bcde	1.51fg
S ₂ W ₁	165.8abcde	81.07abcd	28.88bcde	1.51fg
S ₂ W ₂	173.27ab	73.47cd	26.9bcdefg	1.43fg
S ₂ W ₃	172.67ab	85.67abcd	32.36b	1.7efg
S ₂ W ₄	162.87abcde	73.53cd	21.56gh	1.1367ij
S ₃ W ₀	159.2bcde	77.6bcd	22.03fgh	0.89j
S ₃ W ₁	164.67abcde	68.93d	28.26bcde	1.15ij
S ₃ W ₂	164.07abcde	71.87d	39.58a	1.54fg
S ₃ W ₃	166.8abcd	71.87d	40.00a	1.57fg
S ₃ W ₄	152.13e	69.87d	30.79bc	1.21hi
Mean	165.66	80.47	27.39	1.72
LSD (5%)	14.33	18.21	5.99	9.64
CV	5.24	13.71	13.27	0.27

Where-PH,FPH,LA and LAI designated for plant height, First pod height, Leaf area and leaf area index ,respectively.CV-Coefficient of variation;LSD = Least Significant Difference; CV = Coefficient of Variation; Means values followed by the same letter(s) within a column are not significantly different at 0.05 probability level.

4.3.3.Height to first pod (cm)

Plant height to the first pod reflects the ability of the cultivars to be mechanically harvested. Height to first pod was significantly ($P < 0.05$) affected by interactions of inter rows spacing and weeding regimes (Appendix Table 1). Highest mean values (96.07 cm) was obtained from the highest plant density or 30cm inter row spacing while the lowest first pod height (68.87 cm)was obtained for the interaction of wider inter-row spacing (60 cm) and herbicide treatment supported by one time hand weeding at 40DAE.Hence, the widest inter rows spacing with different weeding regimes resulted in the shortest height to first pod.

The highest value for height to the first pod might be due to increase in inter node length at the highest plant density, as the crops compete for sun light .This result was in agreement with the findings of

Sharifi (2014) from Iran who reported that plant height to the first pod was significantly affected by faba bean genotypes and plant density.

4.4. Effects of Inter Row Spacing and Weed management on Yield and Yield Components

4.4.1 Number of productive tillers per plant

There was a significant ($P < 0.05$) difference between inter row spacings for number of tillers but weeding regimes and the interaction between spacing and weeding had no significant effect (Appendix table 1). The highest number of tillers per plant (0.64) was obtained from the wider inter row spacing (60cm and 50cm). whereas, the lowest value (0.29) was obtained from the narrowest inter row spacing (30cm) (Table 7).

The production of more productive tillers/branches at the wider spacing might be attributed to the more efficient use of available nutrients, water, and light energy which, could favor more photosynthesis and allocation of carbohydrate for all growth points compared to the closest spacing. In contrast, plants spaced closer gave less number of productive tillers/ branches per plant; the decrease in branch/tiller number was parallel with the increase in inter row spacing.

The potential of tiller production is genetically controlled behavior, but, when combined with wider inter row spacing may lead to a more reduction in competition between faba bean plant and thereby leading to high productive tillers as compared to narrow inter row spacing. The result is in agreement with Al-Suhaibani *et al.* (2013) who reported a maximum number of productive tillers per plant for faba bean under low plant population.

Table 7. Effect of inter rows spacing on Number of productive tillers per plant (NPTPP)

Inter rows spacing	NPTPP
30cm	0.29b
40 cm	0.45ab
50 cm	0.57a
60 cm	0.64a
Mean	0.49
LSD (5%)	0.24
CV	66.47

Where; LSD-Least significant differences; CV = Coefficient of Variation; Means values followed by the same letter(s) within a column are not significantly different at 0.05 probability level.

4.4.2 Number of pods per plant

There was a significant ($P < 0.05$) difference in the number of pods per plant as affected by interaction of inter row spacing and weed management (Table 8). The highest number of pods per plant (12.73) was recorded for the widest inter row spacing (60cm) and twice hand weeding, whereas the lowest value (7.87) was obtained from the narrowest spacing (30cm) with non-weeding.

This finding was in agreement with Hawtin and Webb (1982) who reported that number of pods per plant increased significantly under low planting density, as low planting densities result in high tillering, high number of pods and high seed yield per plant. Similar results have been reported by Fucinman, (1984) and Gah El Rasoul (1986) who noted that low plant density increased the number of pods /plant. This could be due to low competition between plants and between the different parts of individual plant which favour the development of higher number of pods per plant under relatively thin plant density.

An increase in the competition for light and nutrients in high population may lead to a decrease in photosynthesis and so more abscission and development of lower pods per plant. The result of the present study was in line with the findings of Abdel (2008) and Shad et al. (2010) who reported a decrease in the number of pods per plant in faba bean relatively at higher plant densities.

4.4.3 Number of seeds per plant:

Number of seeds per plant was significantly ($P < 0.05$) affected by interaction of inter row spacing and weeding management (Appendix table 1). The highest number of seeds per plant (33.73) was recorded for interaction of wider inter row spacing (50cm) and twice hand weeding followed by 60cm inter row spacing and twice hand weeding (30.13). whereas, the

lowest value(19.47) was obtained from combined application of 40cm inter row spacing and herbicide supplemented by one times hand weeding ,which, was statistically at par with the mean values for the combination of 30cm inter row spacing withunweddedand three times hand weeding (Table 8).

Contrast to this result,Fucinman(1984)reported that the number of seeds per plant of faba bean was insignificantly affected by planting density suggesting, that this character is genetically controlled.

4.4.4. Number of seeds per pod:

Number of seeds per podwas a significantly ($P<0.05$) affected by interaction effect of inter row spacing and weeding management (Appendix table 1). The highest number of seeds per pod (2.84) was found from the interaction of the wider inter row spacing (60cm)and twice hand weeding whereas the lowest number of seeds per pod (2.25) obtained from combined application of 30 inter row spacing and herbicide supplemented by one times hand weeding (Table 8).

The result was similar Hawtin and Webb (1982) indicated that plant population may have effect in reducing the number of seeds per pod under high planting density.Kubure *etal.* (2016)reported number of seedsper pod didnotvarysignificantlyamongthegenotypes, whileittendedtovarywithplantdensityand manualweed management.

4.4.5. Thousand Seedweight

Thousand grain weight of faba bean was significantly ($P<0.05$) influenced by the interaction of inter row planting space and weed management. The mean comparison of the effect of different levels of inter row spacing and weedmanagementon weight of 1000-grains showed that the highest weight (789gm) resulted from the density of17 and 20 plants/m² or 60cm and 50cm inter row spacing, while,the lowestvalue (761gm) was from density of 33plants/m²or 30cm inter row spacing withonetime hand weeding at (Table 8).

Biswas *et al* (2012) reported that in low density of plant, more pods and heavier grains were obtained compared to high density because of better utilization of nutrition and light. The decrease in 1000-grainsweight with increase plant population might be due to non-uniform distribution of light and decrease in leaf area which leads to decrease in rate of photosynthesis and or decrease of reservoir and assimilates mobilization to the reservoirs. The study was in agreement with the findings of El Obied (1997) who reported that low plant density slightly increased the mean 1000seed weight in faba bean under effective weed management.

4.4.6. Above ground dry biomass (kg ha⁻¹)

The maximum aboveground dry biomass yield (10,589.7kg ha⁻¹) was obtained from the treatment combination of widest inter row spacing(60cm) and twice hand weeding(Appendix Table 1). The non-weeded combination with wider inter rowspacing (50cm) resulted in the lowest aboveground dry biomass yield (5874.6 kg ha⁻¹), which was significantly ($P<0.05$) lower than all other treatments with different weeding regimes. The highest aboveground dry biomass yield at the interaction of two hand weeding and widest inter row spacing(60cm) might be due to better condition for the crop to effectively utilize resources as compared to the combined application of 30cm inter spacing and unwedded treatment (Table 8).

This finding was in agreement with that of Shrestha *et al.* (2010) who reported that the removal of weeds from crop at earlier time with optimum population could boost the yield components and yield. On the other hand, the lowest total dry biomass, which was recorded for weedy check with 30cm row spacing, could be due to unavailability of more space for better light interception and competition for nutrients and moisture. It also could be due to high infestation of weed population, which was not controlled during crop growth period. This finding was in line with the study of Naveed *et al.* (2008) who reported that weeds are naturally strong competitors and compete with crops for space, nutrient, moisture, light and carbon dioxides and thus could reduce dry matter accumulation in crop straw and grains.

4.4.7. Harvest index (%)

Interaction of row spacing and weeding management significantly ($P < 0.05$) affected harvest index (Appendix Table 1). The wider inter row spacing (50cm) combined with twice hand weeding gave higher harvest index (40.03%). The lowest harvest index (30.52) was observed for narrowest spacing (30cm) under non-weeded condition (Table 8). Contrary to this result Khamooshiet *al.* (2012) reported non-significant effect of plant density on harvest index of faba bean. On the other hand weber (1996) reported that lower plant population tended to increase harvest index in soybean.

4.4.8. Grain yield (kg ha^{-1})

The interaction row spacing and weed management was significant ($P < 0.05$) for grain yield (Table 8). The lowest grain yield ($1,974 \text{ kg ha}^{-1}$) was recorded for 30 cm inter row spacing with non-weeded plot. The highest grain yield ($3911.7 \text{ kg ha}^{-1}$) was recorded for 60 cm row spacing with twice hand weeding. Reduced crop weed competition due to effective weed control by twice hand weeding resulted in better growth and development of the crop. Therefore, Wider inter row spacing combined with twice hand weeding significantly gave higher number of pods plant⁻¹, higher Number of seeds pod⁻¹, and maximum 1000 seed weight which contributed to the production of higher grain yield compared to all other treatments (Table 8).

Narrowest inter spacing (30 cm) combined with non-weeded plots gave lowest yield probably due to high weed competition with faba bean and with each other for resources required for plant growth and development. The highest yield advantage was obtained from combined application of 60cm inter row spacing and twice hand weeding, which was 553.7 kg ha^{-1} or 16.49% as compared to the control.

On the other hand, higher yields of faba bean obtained at lower density may be due to larger number of pods per plant and higher seed weight. The high yielding performance of the variety used in the present study has also been reported by Teame et al. (2017).

These results were in agreement with the findings of Al-Rifaeet al (2004) and Thalji (2006)

who reported that low plant density produced a higher yield in faba bean. However, these results are in contrast with those of Khalil *et al.* (2010) and Dahmardehet *al* (2010), who reported high yields of faba beans at higher planting density.

In agreement with the results of the present study, Al-Suhaibani *et al.* (2013) reported that when the planting density is too low each individual plant may perform at its maximum capacity by producing productive tillers/branches. Dahmardeh *et al.* (2010) have also found high seed yield of faba bean in sandy loam soil at lower plant density (20 plants m⁻²). However, Gezahegn *et al.* (2016) found highest seed yield of faba bean at Vertisol in 30 cm inter and 8 cm intra row spacing compare to 40 cm inter and 10 cm intra row spacing.

Table 8. Interaction effects of Spacing and weed management on Yield and Yield components

Treatments	YD(kgha ⁻¹)	BM(kgha ⁻¹)	HI (%)	TSW(g)	NPPP	NSPP	NSPPo
S ₀ W ₀	1974h	6484.6ij	30.52g	761d	7.87c	19.67d	2.67abc
S ₀ W ₁	2921.3ef	9140.4cd	32.597fg	761d	8.53bc	20.73cd	2.58abcd
S ₀ W ₂	3365c	10097.6ab	33.36ef	765.3d	8.87bc	22.47bcd	2.55abcd
S ₀ W ₃	2581.3g	7987.8efg	32.33fg	779ab	8.33bc	19.6d	2.37cd

S ₀ W ₄	3152.3cd	9140.4cd	34.49def	774c	8.87bc	19.47d	2.25d
S ₁ W ₀	2895f	7861.9fg	36.86bcd	774c	8.4bc	20.73cd	2.49abcd
S ₁ W ₁	3124de	8010.5efg	39.05ab	784ab	9.93abc	25.53abcd	2.62abcd
S ₁ W ₂	3358c	8666.7cdef	38.75ab	774c	9.4abc	24.73abcd	2.6abcd
S ₁ W ₃	3291.3cd	8852.4cde	37.21bc	774c	8.47bc	23.13bcd	2.83ab
S ₁ W ₄	2912.7ef	7849.5fg	37.1bc	774c	11.53ab	28.87abc	2.49abcd
S ₂ W ₀	1977h	5874.6j	33.66ef	789a	10.87abc	26.8abcd	2.50abcd
S ₂ W ₁	2642.3g	7451.9gh	35.47bcd	789a	11.67ab	31.47ab	2.66abc
S ₂ W ₂	2906.7ef	7259.8ghi	40.03a	789a	12.67a	33.73a	2.70abc
S ₂ W ₃	2906.3ef	7750.2fgh	37.51bc	789a	9.13bc	22.6bcd	2.47bcd
S ₂ W ₄	2596.7g	6819.9hij	38.06ab	789a	11.53ab	28.87abc	2.50abcd
S ₃ W ₀	2745.7fg	7428.3ghi	36.98bc	774c	9.47abc	25.53abcd	2.69abc
S ₃ W ₁	3195cd	8008efg	39.92a	789a	10.13abc	28.4abcd	2.39cd
S ₃ W ₂	3911.7a	10589.7a	36.98bc	789a	12.73a	30.13ab	2.84a
S ₃ W ₃	3669b	9612.3bc	38.20ab	789a	11.13abc	28.4abcd	2.69abc
S ₃ W ₄	3194.7cd	8540.5def	37.4bc	789a	11.4ab	29.67abc	2.66abc
<i>Mean</i>	2966	8171.35	36.32	779.77	10.05	25.53	2.58
<i>LSD(5%)</i>	218.52	957.12	2.4075	5.30	3.49	9.18	0.37
<i>CV</i>	4.46	7.10	4.02	0.41	21.09	21.79	8.69

Where: TSW, YD, BM, HI, NPPP, NSPP, NSPPo- Designated for thousand seed weight, Yield, Dry biomass, harvest index, Number of pod per plant, number of seed per plant, Number of seed per pod respectively; CV-coefficient of Variation, LSD-least significant difference, values with the same letter/s within column statistical not vary at P<0.05

4.5. Correlation Analysis among Traits

The relationships among quantitative traits of faba bean plants and weed parameters at different stages are presented in (Appendix Table 3). Seed yield was significantly and positively correlated with plant height (0.25**), number productive tillers per plant ($r=0.21^{**}$), dry biomass ($r=0.87^{**}$) and harvest index ($r=0.42^{**}$) but it was significantly and negatively correlated with first pod bearing height ($r=0.26^{**}$) Weed density at 40DAE ($r=0.52^{**}$), Weed dry Weight at 40DAE ($r=0.52^{**}$), Weed density at 60DAE ($r=0.49^{**}$) and Weed dry Weight at 60DAE ($r=0.53^{**}$). These results gave a clear indication that the yield components were very closely associated with each other but negatively associated with weed density and weed dry weights (Appendix Table 3).

This result was in close agreement with previous findings by several authors (Tadesse *et al.*, 2011; Yassin, 1973), where grain yield was reported to have been strongly associated with the major yield components. Similarly, the findings of Vandana and Dubeyin (1993) indicated positive association of seed yield per plot with plant height, pods/plant, productive tillers per plant and number of seeds/plant.

Similarly, it has been reported that seed yield of a faba bean crop is the product of number of plants per unit area and four plant components: number of pod-bearing nodes/plant, number of pods/pod bearing node, number of seeds/pod and average seed weight (Sjodin, 1976; Thompson and Taylor, 1977).

The most stable of these plant components in relation to environment is the number of ovules per pod, and average seed weight is next most stable. It is well known that compensation for reduction in one component of yield may occur through any one or several others. For the same yield, there were large differences in the magnitude of the various components (Sjodin, 1976; Thompson and Taylor, 1977). In line with this study, it has been reported that primary components of seed yield in legumes are number of pods/plant, number of seed /pod and seed weight (Graff and Rowland, 1987).

4.6. Partial Budget Analysis

In order to evaluate the economic benefits of the different management practices, partial budget analysis was done. In economic analysis, farmers require a minimal rate of return of 100%, representing an increase in net return of at least one birr for every one birr invested, to adopt new agricultural technology (CIMMYT, 1988). Thus, to draw recommendations for farmers from Marginal analysis in this study, 100% return to the investment is reasonable and minimum acceptable rate of returns since farmers' in the study area usually well-defined optimum plant density with optimum weeding management with or without agrochemical to manage weeds in order to maximize yields and economic return.

The total costs for seed and weed management vary between the treatments but all other costs were assumed constant all over the treatments. According to the partial budget analysis, the maximum total variable cost was incurred from 30 cm inter row spacing or 33 plants m^{-2} and three times hand weeding at 20, 40 and 60 DAE. The highest total costs that vary in 30 cm inter row spacing under three times hand weeding was due to the highest cost incurred for the three times manual weeding and seed costs as compared to the other treatments (Table 9).

The highest (66,817 ETB ha^{-1}) net benefit was obtained from widest (60 cm) inter row spacing or 17 plants m^{-2} under twice handweeding at 20 and 40 DAE. In contrast, the lowest (29,925 ETB ha^{-1}) net benefit was recorded for 30 cm inter-row spacing or 33 plants m^{-2} and unweeded combination of treatment (Table 9).

Dominance analysis showed that all inter row spacing combined with all different weed management except 60 inter row spacing combined with one and two times hand weeding was dominated as their net benefits were less than those of treatments with lower variable costs. Hence, all dominated treatments were eliminated from further consideration for marginal rate of return analysis.

All undominated treatments gave marginal rate of return (MRR) which was greater than the minimum acceptable rate of return (100%). The highest MRR (3125%) was obtained from 60 cm inter row spacing and twice hand weeding, followed by 60 cm inter row spacing and one times hand weeding.

Therefore, 60cm inter-row spacing (17 plants m⁻²) and twice hand weeding gave the highest net benefit (66,817ETBha⁻¹) and percent of MRR (3125%) which was higher than the minimum rate of return (100%). The result was in agreement with that of Al-Suhaibaniet *al.* (2013) who found a higher profit of faba bean from lower seed rate.

Table9. Partial budget analysis for the combined effects of inter row spacing and weed management on faba bean grain yield in Omo Nada in 2018.

Treatments	AGY(kgha-1)	GFB(ETB)	NB(ETB)	MRR (%)
S0W0	1776.67h	35532h	29925j	D
S0W1	2629.33ef	52584ef	46577fg	D
S0W2	3028.67c	60570c	54163cd	D
S0W3	2323.33g	46464g	39657i	D
S0W4	2837.33cd	56742cd	50285def	D
S1W0	2605.67f	52110f	47910ef	D
S1W1	2811.67de	56232de	51632cde	D
S1W2	3022c	60444c	55444c	D
S1W3	2962cd	59244cd	53844cd	D
S1W4	2621.33ef	52428ef	47378fg	D
S2W0	1779.33h	35586h	32226j	D
S2W1	2378.33g	47562g	43802gh	D
S2W2	2616ef	52320ef	48160ef	D
S2W3	2615.67ef	52314ef	47754ef	D
S2W4	2337g	46740g	42530hi	D
S3W0	2471fg	49422fg	46629fg	D
S3W1	2875.33cd	57510cd	54317c	1922
S3W2	3520.33a	70410a	66817a	3125
S3W3	3302.33b	66042b	62049b	D
S3W4	2875.33cd	57504cd	53861cd	D
mean	2669.43	53388.00	48748.00	
LSD (5%)	92.43	1849.10	1849.10	
CV	4.46	4.46	4.89	

AGY=Adjusted Grain yield; GFB = Gross field benefit; NB = Net benefit; D=Dominated treatment; ETB = Ethiopian Birr; Price of Seed= 21birr kg⁻¹; Price of Dual Gold herbicide = 450birr kg⁻¹, Wage rate = 50 Birr man-day⁻¹; Retail price of grain = 20 birr kg⁻¹; 1USD = 27.80 ETB.

5. SUMMARY AND CONCLUSION

Faba bean is the least expensive source of protein for the people in Ethiopia. It is widely cultivated in the farming communities of Jimma zone. However, lack of optimum plant population with appropriate weed management practices is the major challenge for the farmers in Omonada area. Thus, the study was done to determine economic optimum interactions of inter row spacing and weeding regimes for faba bean production in the study area.

Based on the result, variation of inter row spacing and weeding regimes had significant effects on growth, yield and yield components of faba bean in clay soil. The highest seed yield was recorded in 60 cm inter row spacing and twice hand weeding at 20 and 40 DAE. Therefore, 60 cm inter row spacing and twice hand weeding can be recommended for obtaining high yield of faba bean in clay soil of study area.

Weed pressure is the main factor that influences production and productivity of faba bean in the area. Integrated weed management approaches is the best option for effective and sustainable weed control, of which, cultural practice is one of the best strategy for the control of weed, particularly in areas where access to post or pre-emergence herbicide is very limited.

The result of this experiment, which focused on different weed control practices, revealed that hand weeding twice at 20 and 40 DAE with wider (60cm) inter row spacing or low plant density ($166,667 \text{ plants ha}^{-1}$) of faba bean resulted in highest yield advantage equals to 553.7 kg ha^{-1} or 16.49% as compared to control and hence recommended for the experiment area.

From economic point of view, 60cm inter row spacing or ($166,667 \text{ plants ha}^{-1}$) and twice hand weeding at 20 and 40 DAE gave highest net benefit with acceptable MRR (%). Thus, twice hand weeding and a plant density of $166,667 \text{ plants ha}^{-1}$ (60cm x 10cm) were found to be better both agronomically and economically for faba bean producing farmers in the study area.

However, as this study was conducted for one season and at one location, further study need to be done over seasons and locations to determine optimum plant populations and weed management options for better recommendation to increase faba bean production and further ascertain their effects on growth, yield and yield components of faba bean.

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7. APPENDICES

APPENDIX TABLE 1. MEAN SQUARES OF ANALYSIS OF VARIANCE FOR WEED AND FABA BEAN PARAMETERS AS AFFECTED BY INTER ROW SPACING AND WEED MANAGEMENT AND THEIR INTERACTION IN OMONADA DURING 2018 CROPPING SEASON.

SN	Parameters	Source of variation				CV (%)
		Spacing (3)	Weeding frequency(4)	Spacing ×weeding frequency(12)	Error(38)	
	weed density m^{-2}					
1	20DAE	47.0362ns	5903.87257*	28.18372**	19.48789	16.64
	40DAE	29.68808ns	4114.22418*	70.41702**	34.1344	26.3
	60DAE	50.69588*	3391.91933*	72.63621**	4.5336	13.01
	weed dry weight($g m^{-2}$)					
2	20DAE	41.745202ns	1200.325986*	13.82122**	1.818473	11.81
	40DAE	68.77871*	4098.95386*	52.64902**	12.01626	18.87
	60DAE	97.00979*	7669.26837*	106.42429**	7.48298	14.76
3	TSW	1375.93*	122.39*	89.73**	10.12	0.41
4	YD	1612698.8*	1559701.71*	174035.56**	15450.21	4.19
5	BM	9531018.5*	8102578.44*	1583751.13**	326757.98	7
6	HI	92.25*	13.81*	6.12**	2.21	4.09
7	PH	53.83*	181.11*	486.07**	78.26	4.43
8	FPH	712.90*	134.45*	47.52*	127.24	14.02
9	NPTPP	0.35*	0.37ns	0.23 ^{ns}	0.11	66.48
10	NPPP	23.95**	7.59*	2.58*	4.07	21.09
11	NSPP	228.58*	49.88ns	15.69 ^{ns}	26.82	21.79
12	NSPPo	0.08*	0.06*	0.07**	0.05	8.87

13	DF	20*	0.01 ^{ns}	299.69 ^{ns}	0.17	1.4
14	DM	245*	0.02 ^{ns}	38.68 ^{ns}	0.12	1.74
15	LA	192.79*	142.52*	46.54**	11.46	12.36
16	LAI	5.54*	2.92*	2.56**	0.11	8.97
17	AGY	1305805.8*	1263144.558*	141052.092**	12508.59	4.19
18	GFB	522514411*	505343354*	56387523**	5005867	4.46
19	NB	628369405*	452715704*	56387523**	5005867	4.89

ns, * and ** are non-significant, significantly different at 5% P level and significantly different at 1% P level, respectively; Figures in parentheses are the degree of freedom. DAE=Days after emergency; TSW=Thousand seed weight; YD=Grain yield; BM=total dry biomass ;HI=harvest index ;PH=plant height; FPH=first pod setting height; NPTTP=Number of productive tillers per plant ;NPPP=Number of pods per plant; NSPP=Number of seeds per plant; NSPPo=Number of seed per pod; DF=Days to flowering; DM=days to physiological maturity; LA=leaf area; LAI=Leaf area Index;AGY=Adjusted Grain yield; GFB=Gross field benefitting=Net benefit

Appendix table 2.Monthly average air temperature and rainfall at Omo nada during the crop growing season of 2018

Month	Rainfall (mm)	Min. Temp. (°C)	Max. Temp. (°C)	Mean Temp. (°C)
January	66.2	11.5	26.4	18.95
February	71.3	10.1	26	18.05
March	82.2	10.3	24.1	17.2
April	77.6	10.4	25.6	18
May	114.2	10.4	25.6	18
June	188.4	10.2	26.1	18.15
July	190.3	10.7	24.6	17.65
August	179.1	11.5	28	19.75
September	101	11.2	26.8	19
October	124	10.8	26.6	18.7
November	55	10.6	28.3	19.45
December	27	9.5	28.2	18.85
Mean	1276.3	10.6	26.36	18.48

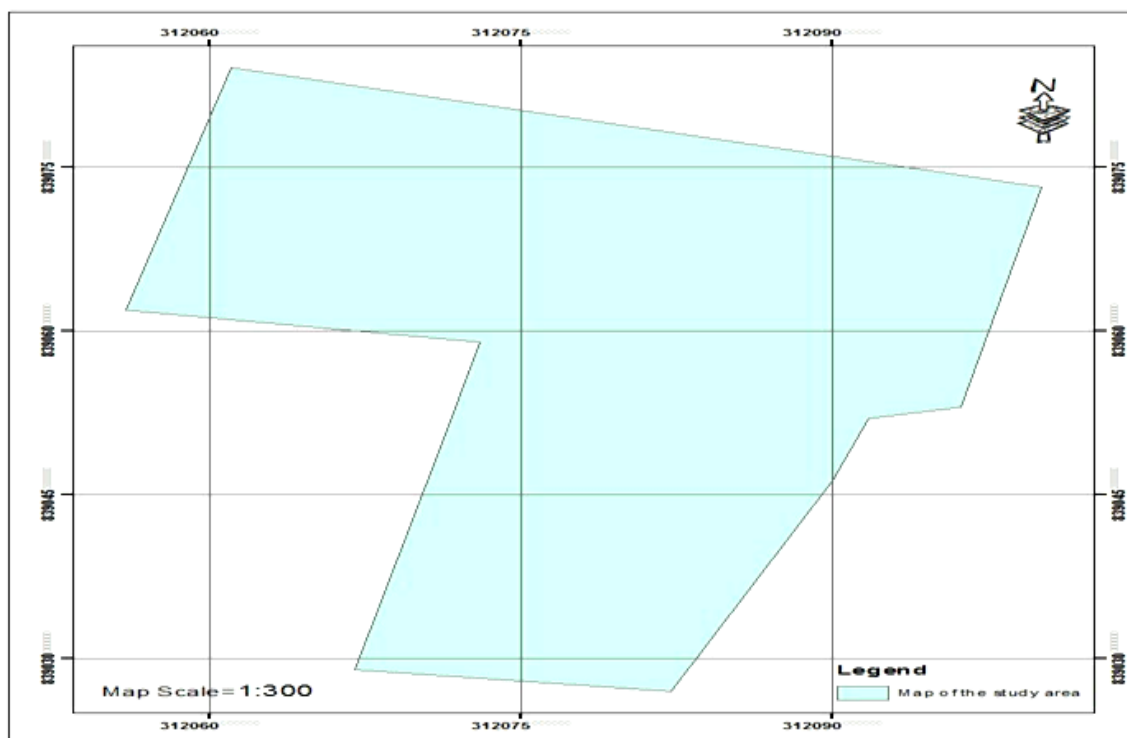
Source: Western Oromia meteorology Service Center Jimma, 2018.

Appendix Table 3. Pearson correlation coefficients among different growth, yield, and yield components and weeds parameters of faba bean in 2018

	20DAE(NW)	20DAE(WD)	40DAE(NW)	40DAE(WD)	60DAE(NW)	60DAE(WD)	TSW	YD	BM	HI	PH	FPH	NPTPP	NPPP	NSPP	NSPPo	DF	DM	LA	LAI
20DAE(NW)	1	0.98**	0.57**	0.58**	0.58**	0.68**	-0.13ns	0.18ns	-0.15ns	-0.10ns	0.09ns	0.15ns	-0.16ns	-0.16ns	-0.10ns	0.16ns	0.08 ns	0.08ns	-0.01ns	-0.15ns
20DAE(WD)		1	0.53**	0.56**	0.55**	0.66**	-0.11ns	-0.14ns	-0.13ns	-0.07ns	0.08ns	0.11ns	-0.13ns	-0.15ns	-0.09ns	0.18ns	0.10 ns	0.10ns	0.03ns	-0.17ns
40DAE(NW)			1	0.94**	0.91**	0.87**	-0.27**	-0.52**	-0.46**	-0.21ns	-0.09ns	0.10ns	-0.35*	-0.01ns	0.01ns	0.06ns	-0.01 ns	-0.00ns	-0.40**	-0.27*
40DAE(WD)				1	0.96**	0.95**	-0.21*	-0.52**	-0.47ns	-0.19*	-0.17*	0.07ns	-0.29*	-0.04ns	-0.04ns	0.01ns	0.06 ns	0.06ns	-0.40**	-0.39**
60DAE(NW)					1	0.96**	-0.27	-0.49**	-0.45ns	-0.17ns	-0.15ns	0.09ns	-0.34**	-0.09ns	-0.08ns	0.01ns	-0.01 ns	-0.00ns	-0.42**	-0.336
60DAE(WD)						1	-0.25**	-0.53**	-0.46**	-0.25**	-0.19*	0.14ns	-0.32**	-0.15ms	-0.15ns	0.01ns	0.03 ns	0.03ns	-0.39**	-0.318
TSW							1	0.14ns	-0.14ns	0.54**	0.03ns	-0.39**	0.34**	0.41**	0.41**	-0.01ns	0.76**	0.76**	0.52**	-0.50**
YD								1	0.87**	0.42**	0.25*	-0.26*	0.31**	0.38**	0.27*	0.15ns	0.01ns	0.02ns	0.53**	0.07ns
BM									1	-0.06ns	0.27*	-0.1ns	0.06ns	-0.03ns	-0.01ns	0.05ns	-0.19*	-0.19*	0.42**	0.35**
HI										1	0.22*	-0.35*	0.38**	0.32**	0.39**	0.19*	0.38**	0.38**	0.25*	-0.50**
PH											1	0.19ns	0.04ns	0.02ns	0.07ns	0.09ns	-0.12*	-0.12*	-0.01ns	0.13*
FPH												1	-0.37**	-0.5**	-0.5**	-0.11ns	-0.41**	-0.40*	-0.29*	0.39**
NPTPP													1	0.14ns	0.13ns	0.05ns	0.29*	0.3**	0.25*	-0.21ns
NPPP														1	0.94**	-0.01ns	0.45**	0.44**	0.13ns	-0.43**
NSPP															1	0.31**	0.49**	0.499**	0.18*	-0.48**
NSPPo																1	0.13ns	0.13ns	0.19ns	-0.17ns
DF																	1	0.99**	0.40**	-0.75**
DM																		1	0.41**	-0.75**
LA																			1	0.1*
LAI																				1

* = Significant at P < 0.05; ** = Significant at P < 0.01; ns=non-significant; DAE=Days after emergency; NW=weed density per m⁻²; WD=weed dry weight(gm⁻²); TSW; thousand seed weight=seed yield; HI=Harvest index; PH=Plant height; FPH=first pod height; NPTPP=Number of productive tillers per plant; NPPP=Number of pods per plants; NSPP=Number of seed per plant; NSPPo=Number of seed per pod; DF=Days to flowering; DM=Days to physiological maturity; LA=Leaf area; LAI=Leaf area index.

Appendix Figure 1: Research Site Map



Appendix Figure 2: Different Pictures during Research periods

