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Assessment of Integrated Weed Management Practices on Weed Dynamics, Yield Components and Yield of Faba bean (*Vicia faba* L.) in Eastern Ethiopia

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ABSTRACT

The experiment was conducted to assess the integrated effects of pre-emergence herbicides and hand-weeding on weed control, yield components, yield, and their economic feasibility for cost effective weed control in faba bean. The experiment consisted of 12 treatments *viz*. pre-emergence s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}) and pendimethalin (1.0, 1.25 and 1.5 kg ha^{-1}), each at three rates metolachlor, s-metolachlor + one-hand-weeding, pendimethalin + one-hand-weeding, two-hand-weeding, complete weed free and weedy checks arranged. The weed flora consisted of broadleaved and sedge with the relative densities of 81.02 and 18.98 % at Haramaya district, and 80.83% and 19.17%, at Gurawa district, respectively. Application of s-metolachlor and pendimethalin 1.0 kg ha^{-1} each supplemented with hand weeding 5 WAE significantly ($p \leq 0.01$) affected the broadleaved weeds, sedges and weed dry weight at both sites. S-metolachlor 1.0 kg ha^{-1} supplemented with hand weeding 5 WAE gave the lowest total number of weeds (8.29 m^{-2}) following the weed free check. Higher grain yield (3555.8 kg ha^{-1}) was produced with s-metolachlor 1.0 kg ha^{-1} supplemented with one-hand-weeding 5 WAE following complete weed-free at Gurawa. The benefit gained from s-metolachlor and pendimethalin at 1.0 kg ha^{-1} each supplemented with one hand weeding 5 WAE were greater than the value recorded from the weedy check by 216% and 198 %, respectively. S-metolachlor 1.0 kg ha^{-1} supplemented with hand weeding 5 WAE treatment resulted in the highest grain yield and economic benefit. However, in case labour is constraint and s-metolachlor herbicide is timely available, pre emergence application of s-metolachlor at 2.0 kg ha^{-1} should be the alternative to preclude the yield loss and to ensure maximum benefit.

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Introduction

Faba bean (*Vicia faba* L.), which is also referred as broad bean, horse bean and field bean, is the fourth most important pulse crop in the world (Sainte, 2011). It has a multipurpose use and is consumed as dry seeds, green vegetable, or as processed food. The crop is an important source of high-quality protein in the human diet, whereas its dry seeds, green haulm and dry straw are used as animal feeds (Sainte, 2011). The main producing countries in the world are Ethopia, Algeria, Morocco, Tunisia, Egypt, Sudan, Iraq, Afganistan, China, India, France, Italy, USA, Mexico, Brazil and Argentina (Chapman and Carter, 1976; Maria and Curbero, 1982; Hawtin and Hebblethwaite, 1983 and Bascur, 1993).

In Ethiopia, faba bean is among the most important pulse crops produced, largely grown in the highlands (1800 - 3000 meters above sea level), where its need for chilling temperature is met. The crop is important in terms of area under production, as a source of protein, restoration of soil fertility by fixing atmospheric nitrogen and as a suitable rotation crop with cereals. Despite the importance of the crop in the traditional farming systems, its average yield under small-holder farmers is not more than 1.6 t ha^{-1} (CSA; 2013), which remains far below the crop's potential (>3 t/ha). The low productivity of the crop is due to several factors, among which poor soil fertility and inadequate plant nutrition, poor seedbed preparation, untimely sowing, sub-optimal weed control, and the lack of improved varieties are the major ones (Berhe et al., 1990; Ghizaw and Molla,1994).

Weeds are plants which compete with crops for nutrients, space, light exerting a lot of harmful effects by reducing the quality and quantity of the crop if their populations are left uncontrolled (Halford et al.,2001; Kavaliauskaite and Bobinas, 2006). The major problem facing the production of faba bean in Ethiopia is weeds, because of the low competitive ability of the bean during its early stages of growth. Uncontrolled weed populations can substantially reduce the yield of the faba bean up to 80% (Mohamed, 1995). Integration of weed control methods is an effective and workable practice that is ecologically and economically viable to the farmers. Herbicides constitute a highly efficient technique for controlling weeds hence increasing yields, improving quality and reducing labour in crop production (Sill, 1982). According to (Arevalo et al., 1992; Cook et al., 1993), several researchers have reported that satisfactory weed control in faba bean was achieved by application of a number of herbicides. However, concerns about crop injury, herbicide carryover, commodity prices, herbicide resistance, environmental and human health hazards associated with herbicides, unavailability of adequate labour during peak period of weeding and difficulty in use of mechanical weeding in heavy soil as well as receiving heavy rains limitations to effective weed management have forced faba bean growers to implement integrated weed management (IWM) practices. These include a combination of cultural, mechanical, and chemical weed management techniques (Burnside et al., 1998).

Efficacy of pendimethalin and s-metolachlor herbicides combined with hand weeding has not yet been evaluated in faba bean growing in mid and highlands of eastern Ethiopia. Hence, the objectives of this study were to evaluate the effect of two pre-emergence herbicides (s-metolachlor and pendimethalin) with or without hand weeding on weed control, and yield components and yield of faba bean and to assess the economic feasibility of supplementing herbicides with hand weeding for effective and cost effective weed management.

Materials and Methods

Description of the Study Sites

The experiment was conducted in the 2014 cropping season at Haramaya (09° 26′ N latitude, 42° 03′ E longitude, and altitude of 2006 meters above sea level) and Gurawa (09°10'51.7"N latitude, 41°47'29.3"E longitude, and altitude of 2355 meters above sea level), in eastern Ethiopia. The soil of the experimental site at Haramaya had organic matter content of 1.0%, total nitrogen content of 0.17%, available phosphorus content of 8.72 mg kg soil^{-1}, pH of 8.13 with sandy loam texture (Cottenie, 1980; Tekalign, 1991; Bethelhem, 2012). Similarly, the soil of Gurawa had organic matter content of 2.8%, total nitrogen content of 0.18%, available phosphorus content of 17.50 mg kg soil^{-1} pH of 6.15 and with clay loam (Cottenie, 1980; Tekalign, 1991; Bethelhem, 2012). Total rainfall during the cropping season was 690 and 1019 mm at Haramaya and Gurawa, respectively. The mean minimum and maximum temperatures during the cropping season were 10.56 and 22.3°C at Haramaya, respectively, with the corresponding records of 9.5 and 21.7 °C for Gurawa (Figure1).

Treatments and Experimental Design

The experiment consisted of 12 treatments *viz*. pre-emergence s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}), pendimethalin (1.0, 1.25 and 1.5 kg ha^{-1}), s-metolachlor at 1.0 kg ha^{-1} + hand-weeding at 5 weeks after crop emergence (WAE), pendimethalin + hand-weeding at 5 WAE, one-hand weeding at 2 WAE, two-hand weeding at 2 and 5 WAE, complete weed free and weedy checks. The herbicides used and their common, trade, and chemical names are shown in Table 1. The treatments were arranged in randomized complete block design with three replications.

Experimental Procedure and Management

The experimental fields were prepared to fine tilth. The gross plot size was 3.2 m × 2.4 m (7.68 m^2) with 40 and 10 cm inter- and intra-row spacing, respectively. The faba bean variety 'Gachana' was planted on 10th and 14th July 2014 at Haramaya and Gurawa, respectively. Fertilizer, di-ammonium phosphate (18% N; 46% P_2O_5) was drilled in furrows at the recommended rate of 100 kg ha^{-1} at planting (Mandefro et al., 2009). The herbicides were applied as per the treatment in the assigned plots one day after planting. Herbicide spray volume with water as carrier was 500 l ha^{-1}. Spraying was done with Knapsack sprayer (15 l capacity) using flat-fan nozzle (XRC8004) . Weeds were removed by hoeing as required in the case of weed free treatment. One row from each side of the plots and four plants from each end of the rows were considered as border. Thus, the net harvestable area was 2.4 m × 1.6 m (3.84 m^2). Harvesting was done manually at harvest maturity on 11th and 29th November 2014 at Haramaya and Gurawa, respectively. The biomass after harvest was sun dried for 10 days and threshing and winnowing were done subsequently.

Data Collection and Analysis

The weed flora present in the experimental fields were recorded from weedy check plots in each replication just before crop flowering by placing a quadrat (0.25 m × 0.25 m) randomly at two spots in each replication and converted into m^{-2}. The species were categorized according to their families with the aid of flora books (Stroud and Parker, 1989; Melaku, 2008) The weeds at this stage were also cut near to the ground and after three days of sun drying, the samples were oven dried at 65ºC to a constant weight to determine aboveground dry weight.

Number of days to flowering was recorded as the number of days from planting to the time when 50% of the 10 pre-tagged plants showed first flower. Days to 90% physiological maturity was recorded in each plot, as the number of days from planting to when 90% of the 10 pre-tagged plant leaves showed yellow colour and their pods turned yellow. Plant height (cm) was recorded from 10 randomly selected plants per plot before harvest from the base of plant to the tip of main stem and was expressed on per plant basis.

Total number of pods in 10 randomly selected plants in each plot was counted at harvest and expressed as the number of pods plant^{-1}. From these pods, the seeds were counted to determine the number of seeds pod^{-1}. Hundred seeds were counted from each plot, and their weight was recorded. Aboveground dry biomass weight was measured at physiological maturity after cutting 10 randomly sampled plants at ground level and sun dried. This was multiplied by the number of plants in the net plot area and converted into kg ha^{-1}.

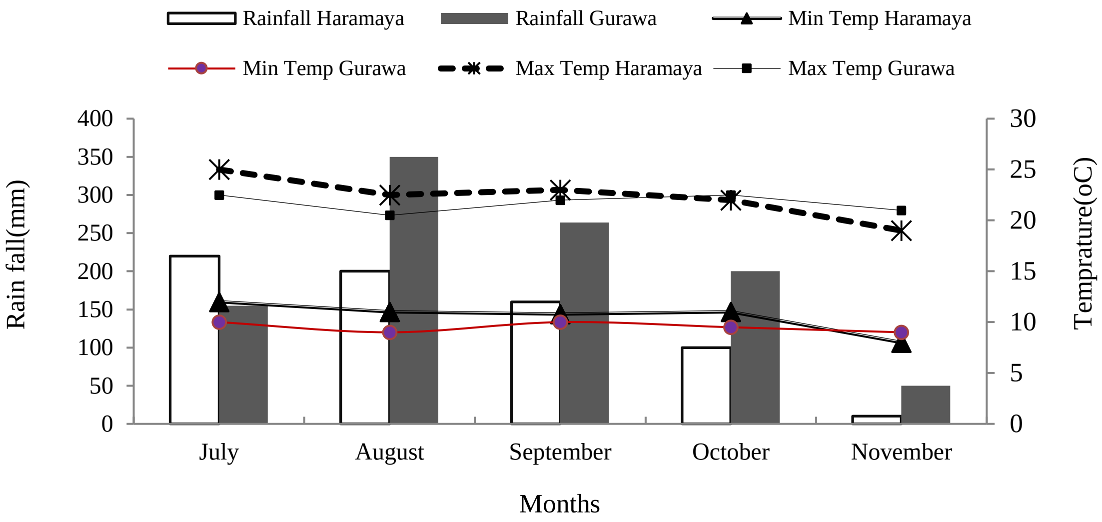

Figure 1 Rainfall (mm), minimum and maximum temperatures (ºC) recorded during the 2014 cropping season at Haramaya and Gurawa districts (Source: Jigijiga Meteorological Station)

Table 1 Description of herbicides used for the experiments

Common name	Trade name	Chemical name
S-metolachlor	Dual Gold 960 EC	[2-chloro-6-ethyl-N-(2-methoxy-1-methylethyl) acet-o-toluidide]
Pendimethalin	Stomp Extra 38.7% CS	[N-(1-ethylpropyl)-2, 6-dinitro-3, 4-xylidine]

CS = Capsule Suspension; EC = Emulsifiable Concentrate

Grain yield (kg) was recorded from each net plot area. The moisture content was determined for each treatment and the grain yield was adjusted at 10%. Harvest index (%) was calculated as the ratio of grain yield to the total aboveground dry biomass yield. The data were subjected to analysis of variance (GLM procedure) using SAS software program version 9.2 (SAS Institute, 2003). Homogeneity of variances was evaluated using the F-test as described by (Gomez and Gomez, 1984) and since the F-test has showed homogeneity of the variances of the two sites combined analysis of variance was used. Least significant difference (LSD) test at 5% probability level was employed to separate treatment means where significant treatment differences existed.

Partial Budget Analysis

The partial budget analysis as described by CIMMYT (1988) was done to determine the economic feasibility of the weed management practices. Economic analysis was done using the prevailing market prices for inputs at planting and for the outputs at the time of crop harvest. It was calculated by taking into account the additional input and labour cost involved and the gross benefits obtained from weed management practices. Average yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could obtain from the same weed management practices as described by (CIMMYT, 1988). The field price of faba bean was calculated as (sale price minus the costs of harvesting, threshing, winnowing, bagging and transportation).The total cost that varied included the sum of cost of herbicides and labour where hand weeding required. The net benefit was calculated as the difference between the gross field benefit (USD ha^{-1}) and the total costs (USD ha^{-1}) that varied.

Results and Discussion

Weeds

The weed species found in the experimental fields were grouped into broadleaved weeds and sedges with the relative densities of 81.02 and 18.98% at Haramaya, and 80.83 and 19.17%, at Gurawa, respectively (Table 2). The predominant broadleaved weeds that infested the experimental plots at Haramaya were *Galinsoga parviflora* Cav. and *Plantago lanceolata* L. with 30.72 and 13.86% relative weed densities, respectively, whereas at Gurawa: *Guizotia scabra* (Vis.) Chiov and *G. parviflora* with 23.31 and 13.53% relative weed densities were the major broadleaved weeds observed. Other weeds included; *Argemone ochroleuca* Sweet (6.63%) at Haramaya; *Equisetum arvense* L. and *Oxalis corniculata* L. each with 5.64% relative density at Gurawa. Only one sedge species (*Cyperus rotundus* L.) was present with relative weed densities of 18.98 and 19.17% at Haramaya and Gurawa, respectively (Table 2). The probable reason for more species occurrence at Gurawa could be the difference in soil type, previous crop, and relatively more rainfall at Haramaya during the early stages of crop growth. Similarly, (Tamado and Milberg, 2000) reported altitude, rainfall, month of planting, number of weeding and soil type were the major environmental/crop management factors that influence the species distribution of weeds in eastern Ethiopia.

Density and Total Numbers of the Sedges and Broadleaved Weeds

Sedge weeds density: The sedge density was significantly (P<0.01) affected in response to weed management practices. The lower sedge density was observed in the plots treated with the application of s-metolachlor at 1.0 kg ha^{-1} supplemented with one hand weeding 5WAE at both sites, which was statistically at par with the weed free check at both sites (Table 3). Further, at Haramaya, no significant differences existed between s-metolachlor and pendimethalin both at 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE. Application of both s-metolachlor and pendimethalin herbicides at low dose (1.0 kg ha^{-1}) supplemented with one hand weeding at 5 WAE resulted in significantly lower sedge density than pendimethalin or s-metolachlor application alone.

The density of sedge decreased significantly with the increase in s-metolachlor and pendimethalin application rates at both sites except between s-metolachlor at 1.5 and 2.0 kg ha^{-1} rates at Gurawa (Table 3). On the other hand, significant differences was existed between one and two hand-weeding at both sites and they were resulted in significant reduction in sedges densities over pendimethalin at 1.0, 1.25 and 1.5 kg ha^{-1} at Haramaya and pendimethalin at 1.0 and 1.25 kg ha^{-1} at Gurawa.

Broadleaved weeds density: Broadleaved weed density showed a significance difference (P<0.01) due to different weed management practices. Similar to sedge density, lowest density of broadleaved weeds was recorded when s-metolachlor at 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE used at both sites. This was statistically as effective as weed free check and pendimethalin at 1.0 kg ha^{-1} integrated with one hand weeding 5 WAE at both sites, while the weedy check plots had the highest density (Table 3). The broadleaved weed density decreased with the increase in herbicide application rates at both sites except between pendimethalin at 1.25 and 1.5 kg ha^{-1} rates at Haramaya. Application of s-metolachlor at 2.0 kg ha^{-1} resulted in significant decrease of broadleaved weed density over s-metolachlor at 1.0 and 1.5 kg ha^{-1} at both sites. Two hand weeding at 2 and 5 WAE was significantly reduced the broadleaved weeds density over one hand weeding 5 WAE, s-metolachlor at 1.0, 1.5 and 2.0 kg ha^{-1}, pendimethalin at 1.0, 1.25 and 1.5 kg ha^{-1} rates but no significant differences existed between pendimethalin at 1.0 + one hand weeding 5 WAE at Haramaya (Table 3).

Total weed density: The total weed density was significantly (P<0.01) affected in response to weed management practices and site while its interaction with the sites had no significant effect. In this respect, the total weed density was significantly lower at Gurawa. This might be due to lower temperature and rainfall at early crop emergence (Figure 1) and lower weed density at Gurawa (Table 2) compared to Haramaya. The lower dose (1.0 kg ha^{-1}) of s- metolachlor and pendimethalin supplemented with one hand weeding were statistically in parity but significantly reduced total weed density than other herbicides and hand weeding treatments (Table 4). Using of s-metolachlor and pendimethalin each with 1.0 kg ha^{-1} and one hand weeding 5 WAE were reduced the total weed density by 96.5% and 93.4%, respectively over weedy check.

Similarly, (Sajid et al., 2012) reported the highest weeds density in weedy check; while, the lowest weeds density was noticed with application of s-metolachlor in pea (*Pisum sativum* L.). The significantly higher weed density with lowest s-metolachlor and pendimethalin application rate at both sites was in line with the finding of (Khan et al., 2003) who stated that reduced rates of herbicide are not advisable under heavy weed pressure. Moreover, at higher rates of application, absorption and translocation of the herbicide might have failed to keep pace with its metabolism compared to lower rates of application, thus weeds surrendered to higher rate of application and proved more effective in reducing the density.

Weed Dry Weight

The effect of weed management practices on weed dry weight was followed similar trends with broadleaved weeds and sedges at both sites. In line with this, the minimum weed dry weight was recorded with s-metolachlor 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE which was statistically in parity with weed free check at both sites (Table 3). Also the results revealed that application of 1.0 kg ha^{-1} of s-metolachlor and pendimethalin each supplemented with one hand weeding was reduced weed dry weight by 96.4 and 93.3% at Haramaya and by 96.7 and 93.6% at Gurawa, respectively over weedy check.

Table 2 Species, families, Density (m^{-2}) and relative density (%) of weeds found in weedy check plots at Haramaya and Gurawa districts during the 2014 cropping season

Weed species	Family	Haramaya		Gurawa	
		WD (m^{-2})	RD (%)	WD (m^{-2})	RD (%)
Broadleaved					
Argemone ochroleuca L.	Papaveraceae	22	6.63	18	6.77
Commelina benghalensis L.	Commelinaceae	25	7.53	21	7.89
Equisetum arvense L.	Equisetaceae	26	7.83	15	5.64
Galinsoga parviflora Cav.	Asteraceae	102	30.72	36	13.53
Guizotia scabra (Vis.) Chiov	Asteraceae	-	-	62	23.31
Medicago polymorpha L.	Fabaceae	23	6.93	-	-
Oxalis corniculata L.	Oxalidaceae	-	-	15	5.64
Plantago lanceolata L.	Plantaginaceae	46	13.86	27	10.15
Solanum nigrum L.	Solanaceae	25	7.53	21	7.89
Total			81.02		80.83
Sedge					
Cyperus rotundus L.	Cyperaceae	63	18.98	51	19.17

WD= Weeds density; RD= Relative density

Table 3 Effects of weed management practices on density (m^{-2}) and weed dry biomass (g m^{-2}) of broadleaved weeds and Sedges in faba bean at Haramaya and Gurawa districts during the 2014 cropping season

Weed management practices	Broadleaved weeds density		Sedges density		Dry weed density	
	Haramaya	Gurawa	Haramaya	Gurawa	Haramaya	Gurawa
S-metolachlor 1.0 kg ha^{-1}	27.92[e]	38.75[e]	43.67[f]	33.75[d]	136.2[f]	131.5[e]
S-metolachlor 1.5 kg ha^{-1}	21.33[f]	28.17[f]	33.7[g]	26.58[e]	104.7[g]	99.3[f]
S-metolachlor 2.0 kg ha^{-1}	15.73[g]	21.7[g]	26.1[h]	21.58[e]	79.6[h]	78.5[f]
Pendimethalin 1.0 kg ha^{-1}	47.5[b]	70.75[b]	91.5[b]	73.5[b]	264.5[b]	261.7[b]
Pendimethalin 1.25 kg ha^{-1}	41.42[c]	54.5[c]	77.17[c]	48.92[c]	225.7[c]	187.6[c]
Pendimethalin 1.5 kg ha^{-1}	38.17[c]	48.25[d]	68.08[d]	39.33[d]	202.2[d]	158.9[d]
S-metolachlor 1.0 kg ha^{-1} + 5 WAE	3.25[ij]	3.67[ij]	5.33j[k]	4.33[gh]	16.3j[k]	14.5[hi]
Pendimethalin 1.0 kg ha^{-1} + 5 WAE	6.08[hi]	7.87[hi]	10[j]	7.53[fg]	30.6[j]	27.9[gh]
One hand weeding at 2 WAE	32.5[d]	44.83[d]	55.17[e]	35[d]	166.8[e]	144.8[de]
Two hand weeding at 2 and 5 WAE	9.58[h]	13.42[h]	17.67[i]	11.72[f]	51.9[i]	45.6[g]
Weed free check	0.0[j]	0.0[j]	0.0[k]	0.0[h]	0.0[k]	0.0[i]
Weedy check	93.33[a]	131.17[a]	146.17[a]	107.67[a]	455.8[a]	433.3[a]
LSD(0.05)	4.495	6.033	6.944	7.121	18.60	23.13
CV (%)	13.85	13.52	12.55	18.03	11.14	15.169

CV= Coefficient of Variation, LSD= Least Significant Difference, WAE= Weeks after emergence, Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

Table 4 Main effect of total weed density at Haramaya and Gurawa districts as influenced by weed management practices during the 2014 cropping season

Treatments	Total weed density
Site:	
Haramaya	75.95[a]
Gurawa	72.75[b]
LSD (0.05)	3.00
Weed management practices:	
S-metolachlor 1.0 kg ha^{-1}	72.04[f]
S-metolachlor 1.5 kg ha^{-1}	54.89[g]
S-metolachlor 2.0 kg ha^{-1}	42.56[h]
Pendimethalin 1.0 kg ha^{-1}	141.62[b]
Pendimethalin 1.25 kg ha^{-1}	111[c]
Pendimethalin 1.5 kg ha^{-1}	96.92d
S-metolachlor 1.0 kg ha^{-1}+ one hand weeding 5 WAE	8.29[j]
Pendimethalin 1.0 kg ha^{-1} + one hand weeding 5 WAE	15.74[j]
One hand weeding at 2 WAE	83.7[5]
Two hand weeding at 2 and 5 WAE	26.19[e]
Weed free check	0.0[k]
Weedy check	239.17[a]
LSD (0.05)	7.887
CV (%)	13.1

CV= Coefficient of Variation, LSD= Least Significant Difference, WAE= Weeks after emergence, Means in column followed by the same letter(s) are not significantly different at 5% level of significance

On the other hand, two hand weeding at 2 and 5 WAE gave significantly minimum weed dry weight of 51.9 and 45.6g m^{-2} at Haramaya and Gurawa, in that order; compared to weed dry weight obtained with the application of s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}), pendimethalin (1.0, 1.25 and 1.5 kg ha^{-1}) and one hand weeding 2 WAE under both sites. However, at Gurawa, no significant difference observed between two hand weeding and pendimethalin 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE. The application of s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}) was significantly performed better than pendimethalin at (1.0, 1.25 and 1.5 kg ha^{-1}) across both sites. (Sajid et al., 2012) also reported better performance of s-metolachlor in reducing weed dry biomass as compared to pendimethalin, metribuzin and isoproturon in pea. (Agegnehu and Fessehaie, 2006) also reported that minimum dry biomass was recorded for pendimethalin, which was statistically comparable with s-metolachlor. At the same time as comparing one hand weeding at 2 WAE with two-hand weeding at 2 and 5 WAE, weed dry weight decreased similar to broadleaved weeds and sedge densities at both sites (Table 3). This might be due to the extent to which the weed species and or the density differed at both sites.

On the other hand, the higher weed dry weight in weedy check might also be due to higher weed density that provided an opportunity to the weeds to compete vigorously for nutrients, space, light, water and carbon dioxide resulting in higher biomass production. These results are in agreement with the findings of (Alfonso et al., 2013) and (Das and Yaduraju, 1999) who reported maximum weed dry weight in weedy check.

Table 5 Effect of weed management practices on days to flowering and physiological maturity of faba bean at Haramaya and Gurawa districts during the 2014 cropping season

Weed management practices	Days to flowering		Days to physiological maturity	
	Haramaya	Gurawa	Haramaya	Gurawa
S-metolachlor 1.0 kg ha^{-1}	48.3^{bcd}	60.0^{cd}	105.0^{bcd}	120.0^{de}
S-metolachlor 1.5 kg ha^{-1}	47.0^{cde}	60.00^{cd}	104.0^{cde}	119.3^{de}
S-metolachlor 2.0 kg ha^{-1}	47.3^{cde}	59.40^{d}	103.3^{def}	118.6^{ef}
Pendimethalin 1.0 kg ha^{-1}	49.6^{b}	62.333^{ab}	106.6^{bc}	124.33^{b}
Pendimethalin 1.25 kg ha^{-1}	48.6^{bc}	62.00^{b}	107.6^{b}	122.6^{bc}
Pendimethalin 1.5 kg ha^{-1}	48.6^{bc}	61.33^{bc}	106.3^{bc}	121.0^{cd}
S-metolachlor 1.0 kg ha^{-1}+ 5 WAE	45.6^{e}	57.0^{f}	102.3^{def}	114.0^{g}
Pendimethalin 1.0 kg ha^{-1} + 5 WAE	46.3^{de}	57.67^{ef}	102.0^{ef}	114.3^{g}
One hand weeding at 2 WAE	47.3^{cde}	60.33^{cd}	103.0^{def}	120.0^{d}
Two hand weeding at 2 and 5 WAE	46.3^{de}	59.0^{de}	102.3^{def}	117.0^{f}
Weed free check	45.3^{e}	56.33^{f}	101.0^{f}	113.6^{g}
Weedy check	52.66^{a}	63.67^{a}	111.3^{a}	127.33^{a}
LSD (0.05)	2.23	1.535	2.749	2.32
CV (%)	2.760	1.513	1.552	1.152

CV=Coefficient of Variation, LSD= Least Significant Difference, WAE= Weeks After Emergence, Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

Table 6 Crop Stand (ha^{-1}), Plant height (cm), Seeds per pod and hundred seed weight (g) of faba bean as influenced by the main effects of sites and weed management practices during the 2014 cropping season

Factors	Crop Stand (ha^{-1})	Plant height (cm)	Seeds per pod	Hundred seed weight (g)
Sites:				
Haramaya	182917^{b}	117.384^{b}	3.425	46.66^{b}
Gurawa	186806^{a}	122.072^{a}	3.530	49.188^{a}
LSD $_{(0.05)}$	3429.8	1.3734	NS	0.9612
Weed management practices:				
S-metolachlor 1.0 kg ha^{-1}	187083^{bcd}	120.00^{cd}	3.48^{abc}	47.80^{ef}
S-metolachlor 1.5 kg ha^{-1}	184583^{d}	118.76^{cde}	3.60^{ab}c	48.27^{def}
S-metolachlor 2.0 kg ha^{-1}	193750^{abc}	116.50^{ef}	3.40^{cd}	49.65^{cde}
Pendimethalin 1.0 kg ha^{-1}	174167^{e}	126.73^{b}	3.13^{de}	41.800^{h}
Pendimethalin 1.25 kg ha^{-1}	175000^{e}	121.60^{c}	3.41^{bc}	44.88^{g}
Pendimethalin 1.5 kg ha^{-1}	183750^{d}	121.77^{c}	3.58^{abc}	45.20^{g}
S-metolachlor 1.0 kg ha^{-1}+ 5 WAE	196667^{a}	113.20^{f}	3.68^{ab}	54.27^{b}
Pendimethalin 1.0 kg ha^{-1} + 5 WAE	194583^{ab}	115.7^{ef}	3.53^{abc}	51.73^{c}
One hand weeding at 2 WAE	185833^{cd}	121.28^{c}	3.48^{abc}	46.66^{fg}
Two hand weeding at 2 and 5 WAE	190417^{abcd}	116.67^{de}	3.650^{abc}	50.23^{cd}
Weed free check	198333^{a}	113.20^{f}	3.73^{a}	57.32^{a}
Weedy check	154167^{f}	131.32^{a}	3.03^{e}	37.30^{i}
LSD (0.05)	8401.3	3.364	0.2675	2.3543
CV (%)	3.91	2.417	6.619	4.22

CV= Coefficient of Variation, LSD= Least Significant Difference, WAE= Weeks After Emergence, NS= Not Significant, Means in column followed by the same letter(s) are not significantly different at 5% level of significance

Crop Phenology and Growth

Days to 50% flowering and 90% physiological maturity: Both days to 50% flowering and 90% physiological maturity were significantly influenced by weed management practices. Faba bean plants at Haramaya attained flowering earlier by 12 days than at Gurawa. This might be due to the higher temperature and rainfall at early crop emergence at Haramaya compared to Gurawa (Figure 1). The results revealed that under weed free check, days to flowering was statistically in parity with 1.0 kg ha^{-1} of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE, two hand weeding at 2 and 5 WAE, s-metolachlor (1.5 and 2.0 kg ha^{-1}) and one hand weeding at 2 WAE at Haramaya. However, at Gurawa, it was statistical at par with s-metolachlor and pendimethalin each at 1.0 kg ha^{-1} and integrated with one hand weeding 5 WAE (Table 5). In weedy check, the shading of crop plants by weeds might have reduced sunlight interception thus prolonged the vegetative growth resulting in delayed days to flowering.

In line with this result, Sunday and Udensi (2013) identified that the plants in not weeded plots took the highest time to reach 50% flowering in cowpea. The influence of weed management practices on 90% days to physiological maturity was followed similar trend to 50% days to flowering at both sites; however, in case of 90% days to physiological maturity, application of 1.5 kg ha^{-1} s- metolachlor had no statistical in parity with weed free check at Haramaya. The physiological maturity of the crop was earlier by 9 and 13 days at Haramaya and Gurawa, respectively over low dose of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE at both sites. The probably reason for differences in maturity across site could be due to the differences in amount and distribution of rain fall, temperature and elevation, while the earlier or delayed maturity in weedy check plots might be due to the shading effect of weeds on crop plants might have reduced interpretation of sunlight thus prolonged the length of growing season resulting in delayed of crop physiological maturity.

The plants in weedy check plots attained significantly higher height (131.32 cm) than others weed management practices. This was followed by the application of pendimethalin at 1.0 kg ha^{-1} (126.73 cm), pendimethalin at 1.25 kg ha^{-1} (121.60 cm) which did not show significant difference with the height measured in plots treated with pendimethalin at 1.25 kg ha^{-1}, one hand weeding at 2 WAE, s-metolachlor 1.0 kg ha^{-1} and s-metolachlor 1.0 kg ha^{-1}, s-metolachlor 1.5 kg ha^{-1} (Table 6). Alike the effect of s-metolachlor at 1.0 kg ha^{-1} and pendimethalin at 1.0 kg ha^{-1} each supplemented with one hand weeding was statistically the same in height as compared to plants height in weed free check plots. This might be due the better broadleaved weeds control in the plots treated with these treatments (Table 3) that might have reduced a severe competition to the crop for growth resources specially the nutrients and moisture as the plants belonging to the same morphology are more competitive than the plants with dis-similar morphology.

Plant Height: Site and weed management practices but their interactions significantly ($P<0.01$) influenced plant height. The faba bean plants at Gurawa were significantly taller by 3.84% than at Haramaya (Table 6). The more height attained by the plants at Gurawa could be due to relatively higher seasonal rainfall than at Haramaya (Figure1).

Grishin et al. (2001) reported a great demand for light, space, moisture and nutrients by plants with similar morphology and physiology. In agreement with present result, (Hock et al., 2006) found differences in plant height due to various intensities of weed competition with crop plants.

Yield Components and Yield

Stand count at harvest: Site and weed management practices had significant influence ($P<0.01$) on stand count ha^{-1}. The crop stand was significantly higher by 2.13% at Gurawa than at Haramaya. The lowest total weed density as well as weed dry weight at Gurawa than at Haramaya might have contributed for the higher survival of crop plants (Table 3 and Table 4). Weed free check gave the highest stand count ha^{-1} (198333) which did not vary significantly with s-metolachlor at 2.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1} + one hand weeding 5 WAE, pendimethalin at 1.0 kg ha^{-1} + one hand weeding 5 WAE and two hand weeding at 2 and 5 WAE (Table 6). The possible reason for the higher stand count in these treatments could be due to their better weed control might have competitive advantage to the crop over the weeds (Table 3 and Table 4). Further, the plants in weedy check had the lowest stand count ha^{-1} (154167), which was significantly lower than the other weed management practices. Weeds might have suppressed the crop plants due to severe competition for growth resources particularly for space and light that suppressed crop plants to the extent that the crop plants could not survive. Two hand weeding at 2 and 5 WAE was not significantly different from the rest of the treatments, except pendimethalin at 1.0 kg ha^{-1} and weedy check treatments. Similar results were reported by (Mekonnen et al., 2015).

Number of pods per plant: Number of pods $plant^{-1}$ had significant effect on the site, weed management practices and their interaction. The highest number of pods per plant (17.0) was obtained from the weed free check plots at Gurawa. This was followed by s-metolachlor1.0 kg ha^{-1} + one hand weeding at 5 WAE at the same site, which had statistically in parity with pendimethalin 1.0 kg ha^{-1} + one hand weeding 5 WAE at Gurawa (Table 7). This might be due to reduced weed competition (Table 3) in plots treated with these weed management practices that made growth resources (nutrient, moisture and light) more accessible for individual plant. As a consequence it might result in higher net assimilation rate thus retaining more flowers. The development of more and vigorous leaves under low weed infestation might have also helped to improve the photosynthetic efficiency of the crop and supported large number of pods (Hodgson and Blackman, 2005). The interaction of two hand weeding at 2 and 5 WAE with site showed significant difference with each other, however the use of this treatment at Haramaya was failed to prove significantly number of pods $plant^{-1}$ compared to one hand weeding across both sites, whereas its interaction with Gurawa was proved significantly better than one hand weeding at 2 WAE.

The lowest number of pods per plant (7.6) was recorded from weedy check at Haramaya, which was significantly lower than all other interactions across both sites. On other hand, number of pods per plant obtained from weedy check at Gurawa was significantly lower than all the interactions, except the interactions of weedy check and pendimethalin at 1.25 kg ha^{-1} at Haramaya as well as pendimethalin at 1.0 kg ha^{-1} at both sites (Table 7). These results are in line with Hadi et al. (2006) who observed an increased number of pods $plant^{-1}$ where weed population was reduced by management techniques. Similarly, (Pereira et al., 2015) and (El-Metwally et al., 2008) stated that the number of pods produced per plant or maintained to final harvest depends on a number of environmental and management practices.

Number of seeds per pod: Number of seeds pod^{-1} had a significant effect due to weed management practices. The number of seeds pod^{-1} not increased significantly with an increase in s-metolachlor and pendimethalin rates except application of pendimethalin at1.0 kg ha^{-1} resulted in significant lower number of seeds pod^{-1} as compared to the value obtained from pendimethalin at 1.25 and 1.5 kg ha^{-1} (Table 6).

Also, the results showed the highest number of seeds pod^{-1} (3.73) was obtained from weed free check plots which was statistically similar with all other treatments other than s-metolachlor at 2.0, pendimethalin at 1.0 kg ha^{-1}, pendimethalin at1.25 kg ha^{-1} and weedy check. Due to the reduced interference of weeds (Table 3 and Table 4); the vigorous leaves might have helped to improve the photosynthetic efficiency of the crop that supported large number of seeds pod^{-1}. Nevertheless, the plants in weedy check gave significantly lower number of seeds pod^{-1} (3.03).

The poor seed filling in weedy check plots might be due to high competition of weeds with crop plant with moisture, light, space and nutrients. The severe weed competition between the weeds and crop in weedy check prominently reduced the nutrient mobility towards grains which might have affected the seed development potential of the faba bean plant. In consistent with this result, (Gupta, 2011) also identified lowest number of seeds pod^{-1}in weedy check plots.

Hundred seed weight: Sites and weed management practices significantly (P<0.01) influenced hundred seed weight while their interaction had no significant effect on 100 seed weight. The seed weight at Gurawa was significantly higher than at Haramaya by 5.42% (Table 6). The relatively optimum rainfall, temperature and suitable soil conditions at Gurawa during the cropping season might have helped faba bean plants to produce well filled and heavier seeds. On other hand, significantly higher hundred seed weight (57.32 g) was obtained from weed free check. This might be due to the plants raised under complete weed free environment utilized available resources to their maximum benefit leading to increased seed weight. Moreover, the more and vigorous leaves under weed free environment might have improved the supply of assimilate to be stored in the seed, hence, the weight of 100 grains increased.

Among the weed control treatments, application of 1.0 kg ha^{-1} of s-metolachlor supplemented with one hand weeding 5 WAE gave the highest seed weight (54.27 g), followed by application of 1.0 kg ha^{-1} pendimethalin supplemented with one hand weeding 5 WAE, two hand weeding at 2 and 5 WAE, s-metolachlor at 2.0 and 1.5 kg ha^{-1}. However, two hand weeding at 2 and 5 WAE did not vary significantly with pendimethalin1.0 kg ha^{-1} + one hand weeding 5 WAE, s-metolachlor at 2.0 and 1.5 kg ha^{-1} (Table 6). Similarly, (Peer et al., 2013) reported that effect of different weed management practices might have resulted in attaining variable hundred seed weight. Meanwhile, significantly lower hundred seed weight (37.30 g) was recorded from Weedy check plots. In agreement with these findings, Peer et al. (2013) and Mekonnen et al. (2015) observed lowest number of hundred seed weight of soybean in weedy check plots.

Grain yield: Faba bean grain yield was significantly (P<0.01) influenced by the site, weed management practices and their interaction. The highest grain yield (3952.5 kg ha^{-1}) was obtained from complete weed free at Gurawa. However, as comparing the weed control treatments, the highest grain yield was recorded with s-metolachlor 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE at Gurawa, which was statistically in parity with pendimethalin1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE and two hand weeding at 2 and 5 WAE at the same site and weed free check at Haramaya (Table 7). Furthermore, interaction effect revealed that no significant difference was existed among the grain yield obtained with two-hand weeding at 2 and 5 WAE and 1.0 kg ha^{-1} of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE at Haramaya and one hand weeding 2 WAE at Gurawa. Among the alone application of herbicides, s-metolachlor at 2.0 kg ha^{-1} recorded highest grain yield (3217 kg ha^{-1}) at Gurawa which was statistically at par with s-metolachlor at 1.5 and s-metolachlor at 1.0 kg ha^{-1} at the same site. Generally, interaction effect of s-metolachlor at all rates with sites were proved grain yield significantly better than pendimethalin at all rates across both sites. The increased grain yield in these treatments might be due to the proper utilization of moisture, nutrients, light and space by the faba bean in the lesser of weed competition.

The results are corroborating with those reported by (Mekonnen et al., 2015; Mengesha et al., 2016). Moreover, the yield obtained at Gurawa, was significantly higher than at Haramaya under all of their respective weed management practices. This difference might have been partially due the differences that existed in number of pods plant^{-1} and hundred seed weight (g) between the sites (Table 6 and Table 7). Similar reports by (Singh and Jolly, 2004) and (Mekonnen et al., 2015) also concluded that proper weed management improve the yield of crops.

Aboveground dry biomass yield: The interaction of weed management practices and sites significantly (P<0.01) influenced aboveground dry biomass. The interaction of weed free check at Gurawa gave highest aboveground dry biomass (9492.6 kg ha^{-1}), however this was at par with the interaction of weed free check at Haramaya (8755.6 kg ha^{-1}), pendimethalin and s-metolachlor each at 1.0 kg ha^{-1} and supplemented with one hand weeding at Gurawa (Table 7). The increased aboveground dry biomass in these treatments might be due to the crop plants utilized the resources more efficiently that resulted in higher final crop stand (Table 6). Similar with present results, (Alfonso et al., 2013) reported good suppression of weed growth by cultural and herbicidal control measures that lead to low competition by weeds for light, space and nutrients by which the crop could utilize both biotic and abiotic resources efficiently, leading to higher dry biomass production. On the other hand, the significantly lower aboveground dry biomass yield (2535.6 kg ha^{-1}) was obtained in weedy check at Haramaya (Table 7). This might be due to severe competition for growth resources resulting in lower availability of nutrients for the crop thus causing reduction in number of tillers thereby low straw yield. Alike number of pods plant^{-1} and grain yield, aboveground dry biomass yield also increased with increasing frequency of hand weeding from one (at 2 WAE) to two (at 2 and 5 WAE) across both sites and a greater significant increase in aboveground dry biomass yield over the weedy check was observed at Gurawa (Table 7). However, increase in both herbicides rates did not bring a significant increase of aboveground dry biomass yield at both sites.

Harvest Index

The interaction effect of weed management practices and the sites revealed significantly highest harvest index (41.6%) with weed free check and s-metolachlor 1.0 kg ha^{-1} with one hand weeding 5 WAE at Gurawa. This had statistically in parity with the harvest index obtained in the interaction of the same site with application of pendimethalin 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE and two hand weeding at 2 and 5 WAE (Table 7). The result also showed no significant variation in harvest index between Haramaya and Gurawa when pendimethalin at 1.0 kg ha^{-1} was applied. Furthermore, at both sites, no significant difference existed among all rates of s-metolachlor applications whereas similar trends were not observed with rates of pendimethalin applications.

Table 7 Interaction effect of site and weed management practices on number of pods plant^{-1}, grain and aboveground dry biomass yield (kg ha^{-1}) and yield loss (%) in faba bean at Haramaya and Gurawa districts during the 2014 cropping season

T	Number of pods plant^{-1}		Grain yield (kg ha^{-1})		Aboveground dry biomass (kg ha^{-1})		Harvest index (%)		Yield loss (%)	
	Haramaya	Gurawa	Haramaya	Gurawa	Haramaya	Gurawa	Haramaya	Gurawa	Haramaya	Gurawa
T1	10.5^{jkl}	12.1^{fgh}	1730.9^{ij}	3040.8^{d}	5238.9^{gh}	8036.9^{b}	33.0^{fg}	38.0^{bcd}	48.0	23.1
T2	11.3^{hijk}	12.7^{efg}	1957.7^{hi}	3045.4^{d}	5626.1^{fgh}	7745.0^{bc}	35.0^{ef}	39.33^{ab}	41.2	23.0
T3	11.2^{hijk}	13.1^{def}	2052.6^{gh}	3217.0^{cd}	5802.8^{efg}	8465.0^{b}	35.3^{ef}	38.0^{bcd}	38.3	18.6
T4	9.1^{m}	9.7^{lm}	1083.3^{l}	2038.4^{gh}	3953.7^{i}	6886.4^{cd}	27.3^{j}	29.66^{hij}	67.4	48.4
T5	10.0^{lm}	10.4^{kl}	1256.7^{kl}	2266.9^{fg}	3957.4^{i}	5970.6^{defg}	31.66^{gh}	38.0^{bcd}	62.2	42.6
T6	10.4^{kl}	10.9^{hijkl}	1338.7^{kl}	2474.7^{ef}	4156.3^{i}	6339.0^{def}	32.0^{gh}	39.0^{b}	59.8	37.4
T7	13.4^{cde}	15.5^{b}	2667.3^{e}	3555.8^{b}	6892.3^{cd}	8535.7^{ab}	38.6^{bc}	41.6^{a}	19.8	10.0
T8	12.5^{efg}	14.4^{bc}	2522.1^{ef}	3431.7^{bc}	6932.5^{cd}	8580.9^{ab}	36.3^{cde}	40.0^{ab}	24.2	13.2
T9	10.6^{ijkl}	11.7^{ghi}	1487.4^{jk}	2713.1^{e}	4619.5^{hi}	6960.4^{cd}	32.0^{gh}	39.0^{b}	55.3	31.4
T10	11.7^{ghi}	13.6^{cde}	2428.8^{ef}	3287.5^{bcd}	6745.2^{cde}	8362.9^{b}	36.0^{de}	39.3^{ab}	27.0	16.8
T11	14.3^{cd}	17.0^{a}	3327.1^{bcd}	3952.5^{a}	8755.6^{ab}	9492.6^{a}	38.0^{bcd}	41.6^{a}	0.0	0.0
T12	7.6^{n}	9.1^{m}	722.8^{m}	1166.0^{l}	2535.6^{j}	3861.8^{i}	28.66^{ij}	30.33^{hi}	78.3	70.5
LSD	1.202		298.5		1026.7		2.345			
CV	6.21		7.68		9.707		3.991			

T: Treatments, CV= Coefficient of Variation; LSD= Least Significant Difference; T1= S-metolachlor 1.0 kg ha^{-1}; T= S-metolachlor 1.5 kg ha^{-1}; T3= S-metolachlor 2.0 kg ha^{-1}; T4= Pendimethalin 1.0 kg ha^{-1}; T5= Pendimethalin 1.25 kg ha^{-1}; T6= Pendimethalin 1.5 kg ha^{-1}; T7= S-metolachlor 1.0 kg ha^{-1}+ one hand weeding 5 WAE; T8= Pendimethalin 1.0 kg ha^{-1} + one hand weeding 5 WAE; T9= One hand weeding at 2 WAE; T10= Two hand weeding at 2 and 5 WAE; T11= Weed free check; T12= Weedy check;WAE= Weeks After Emergence; Means in column and row of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

Table 8 Partial budget analysis to estimate net benefit for weed management practices of faba bean averaged over sites in 2014 cropping season

Weed Management Practices	Average Yield (kg ha^{-1})	Adjusted Yield (kg ha^{-1})	Gross benefit (USD ha^{-1})	Total variable cost (USD ha^{-1})	Net benefit (USD ha^{-1})
S-metolachlor 1.0 kg ha^{-1}	2385.85	2147.27	1645.20	26.28	1618.92
S-metolachlor 1.5 kg ha^{-1}	2501.55	2251.40	1724.97	30.96	1694.01
S-metolachlor 2.0 kg ha^{-1}	2634.8	2371.32	1816.82	35.65	1781.17
Pendimethalin 1.0 kg ha^{-1}	1560.85	1404.77	1076.29	50.34	1025.95
Pendimethalin 1.25 kg ha^{-1}	1761.8	1585.62	1214.88	58.70	1156.18
Pendimethalin 1.5 kg ha^{-1}	1906.7	1716.03	1314.80	67.06	1247.74
S-metolachlor 1.0 kg ha^{-1}+ 5 WAE	3111.55	2800.40	2145.60	85.77	2059.83
Pendimethalin 1.0 kg ha^{-1} + 5 WAE	2976.9	2679.21	2052.76	109.83	1942.92
One hand weeding at 2 WAE	2100.25	1890.23	1448.25	118.98	1329.27
Two hand weeding at 2 and 5 WAE	2858.15	2572.34	1970.87	178.47	1792.39
Weedy check	944.4	849.96	651.20	0.00	651.20

WAE = Weeks after crop emergence; Cost of pendimethalin and s-metolachlor 33.44 and 9.37 USD kg^{-1}, respectively; Spraying 16.90 USD ha^{-1}; Cost of hand weeding and hoeing 2 WAE 48 persons, 35 DAE 24 persons @USD 2.48/ person; Sale price of faba bean 0.88 USD kg^{-1}; Field price of faba bean 0.77 USD kg^{-1}; Cost of harvesting, Threshing and winnowing 7.66 USD 100 kg^{-1}; Packing and material cost 0.27 USD 100 kg^{-1} and Transportation 0.32 USD 100 kg^{-1}

It was found that with pendimethalin at 1.0 kg ha^{-1}, the harvest index was significantly reduced at Haramaya but it had statically in parity with weedy heck at the same site compared to the others weed management practices at both sites (Table 7). However, weedy check plots at Gurawa, resulted in statistically similar harvest index with pendimethalin 1.0 kg ha^{-1} at Gurawa and pendimethalin (1.25 and 1.5 kg ha^{-1}), one hand weeding 2 WAE and weed free check plots at Haramaya. This lower harvest index might be due to severe weed competition with the crop for the growth factors, which restricted the growth and development of the crop in weedy check plots. In contract with this, Mizan et al. (2009) and Mengesha et al. (2016) reported that increased vegetative growth duration and allocation of more assimilates for shoot rather than root growth.

Yield Loss

The amount of grain yield loss in faba bean was affected by weeds in various weed management practices. As comparing weed management practices with each others, the highest yield loss (78.3%) was observed in weedy check plots over weed free check at Haramaya. The next yield loss (70.5%) was obtained from the same treatment but at Gurawa, while comparing to weed free check, the lowest yield loss was recorded from s-metolachlor 1.0 kg ha^{-1} supplemented by one hand weeding at 5 WAE (Table 7). In generally, the minimum yield loss was recorded with the application of 1.0 kg ha^{-1} of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE at both sites. As the applied rates of both s-metolachlor and pendimethalin increases, the percent of the yield loss due to weeds under both sites become decreases. In line with this finding, Patel et al. (2003) and Tesfay Amare (2014) reported that the presence of weeds reduced grain yield by 82% over complete weed free check.

Partial Budget Analysis

An economic analysis on the combined results using the partial budget procedure (CIMMYT, 1988) was done due to grain yield was significantly affected (Table 7) by weed management practices. The results in Table 8 of this study showed that the two-hand weeding at 2 and 5 WAE had maximum (178.47 USD ha^{-1}) total variable cost. This was followed by one hand weeding at 2 WAE and pendimethalin at1.0 kg ha^{-1} integrated with one hand weeding 5 WAE which had 118.98 and 109.83 USD ha^{-1} total variable cost, respectively. The higher cost with hand weeding and hoeing than the other treatments was due to the difference in the cost incurred for manual weeding. The highest (2145.60 USD ha^{-1}) gross benefit was obtained when1.0 kg ha^{-1} of s-metolachlor supplemented with one hand weeding at 5 WAE was used. This was followed by pendimethalin 1.0 kg ha^{-1} + one hand weeding 5 WAE (2052.76 USD ha^{-1}) and two hand weeding at 2 and 5 WAE (1970.87USD ha^{-1}). The higher gross income in these treatments than in the other treatments was due to their higher yield.

The lowest (651.20 USD ha^{-1}) gross return was recorded in the weedy check plots. Similar to the gross benefit, the highest (2059.83USD ha^{-1}) net benefit was obtained with the application of s-metolachlor 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE. This was followed by pendimethalin 1.0 kg ha^{-1} supplemented with one hand weeding 5 WAE (1942.92USD ha^{-1}) and two hand weeding at 2 and 5 WAE (1792.39 USD ha^{-1}). The highest benefit in these treatments was due to the increased gross benefit despite their higher variable input cost. Similar results were also obtained when total variable input cost of the treatments was considered.

Conclusions

Application of 1.0 kg ha^{-1} of s-metolachlor and pendimethalin each integrated with one hand weeding at 5 WAE are the most appropriate methods for effective weed management and economic benefit of faba bean. Thus, controlling weeds with application of s-metolachlor and pendimethalin each at 1.0 kg ha^{-1} supplemented with one hand weeding at 5 WAE proved to increase the grain yield and economic benefit of faba bean. Nevertheless, in case labour is constraint and s-metolachlor herbicide is timely available, pre- emergence application of s-metolachlor at 2.0 kg ha^{-1} should be the alternative to preclude the yield loss and to ensure maximum benefit. The results of this study further imply that, if farmers are unable to carrying out weeding at early stage due to labour competition, low dose of herbicides at early stage are the best alternative they could use for enhancing the yield of the crop in the study area later on they can supplement with hand weeding.

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