Journal of Science and Sustainable Development (JSSD), 2016, 4(1), 1-14

ISSN: 2304-2702 (print); 2414-4479 (online)
DOI: https://doi.org/10.20372/au.jssd.4.1.2016.051

Evaluation of Integrated Weed Management Practices on Weeds and Yield of Common Bean (*Phaseolus vulgaris* L.) in Eastern Ethiopia

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Abstract

The study was conducted in 2012 cropping season at Haramaya and Hirna, eastern Ethiopia, to evaluate the possibility of supplementing low dose application of s-metolachlor and pendimethalin with hand weeding for effective and economic weed control in common bean. The experiment comprised of 12 treatments viz. preemergence s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}), pendimethalin (1.0, 1.25 and 1.5 kg ha^{-1}), and low dose of herbicides (1.0 kg ha^{-1} each) supplemented with hand weeding four weeks after crop emergence (WAE), one hand weeding two WAE, two hand weeding at two and four WAE, weed free and weedy check arranged in randomized complete block design with three replications. The weed flora assessment showed the presence of broadleaved and sedges with relative densities of 85.7 and 14.3% at Haramaya, and 70.0 and 30.0%, at Hirna, respectively. Interaction of sites and weed management practices significantly affected weed density and dry weight. Days to flowering, hundred seed weight and grain yield were significantly influenced by weed management practices. Interactions of sites with weed management practices significantly affected number of pods per plant and aboveground dry biomass. Plants in weed free treatment flowered earlier by six days, and grain yield increased by 53.3% when compared with weedy check. The benefit gained from s-metolachlor at 1.0 kg ha^{-1} with one hand weeding four WAE was 92.6% greater than from the value obtained from the weedy check treatment. Farmers could use s-metolachlor at 1.0 kg ha^{-1} supplemented with one hand weeding four WAE to maximize economic benefit.

Keywords: Cost benefits analysis; Hand weeding; Low dose, Pendimethalin; S-metolachlor.

Introduction

Common bean is not known to be a strong competitor with weeds; weed interference can result in large yield losses ranging from 58 to 99% (Ahmadi et al., 2007; Dawit et al., 2011; Mukhtar, 2012). Moreover, weed interference reduced the canning quality of the crop (Abiye and Fasil, 2009) harvest efficiency and may stain white bean, resulting in reduced market value (Burnside *et al*., 1994). Therefore, effective weed management is very crucial for profitable common bean production.

The inability to control weeds by hand, declining labour availability and the drudgery involved in weeding during wet and/or dry conditions encourage and increasingly justify the use of herbicides (Mashingaidze et al., 2003). The importance of herbicides for improving crop productivity is not only popular in situations where labour is scarce and expensive, but also where labour is plentiful and cheap because of factors such as morphological similarity of the crop and weeds plus crop damage due to mechanical weeding. Further, the herbicides control weeds effectively and remove weeds having extensive root system, and is less costly compared to manual weeding (Bhan and Mishra, 1993).

Burnside et al., (1994) reported the adoption of integrated weed management practices by common bean growers due to concerns such as; crop injury, herbicide carryover, commodity prices, herbicide resistance, and environmental and human health hazards associated with herbicides. The implementation integrated weed management practices include a combination of cultural, mechanical, and chemical weed management techniques. To implement these weed management techniques, growers must consistently get acceptable weed control with a focus on increased profitability (Blackshaw et al., 2000).

Several studies had reported the effectiveness of integrated weed management methods in increasing common bean yield. Dawit et al. (2011) reported that the integrated use of pendimethalin and s-metolachlor (each at 1.0 kg ha^{-1}) with one hand weeding 35 days after sowing increased the yield of common bean by 67% and 68%, respectively compared to weedy control. Peter et al. (2008) also reported that s-metolachlor at 1.05 kg ha^{-1} followed by cultivation gave better profit margin.

However, pendimethalin and s-metolachlor application at different rates integrated with hand weeding have not been evaluated in eastern Ethiopia. Therefore, this experiment was conducted to evaluate the effect of s-metolachlor and pendimethalin application on weeds, and yield of common bean and to determine the effectiveness of supplementing low dose of herbicides with hand weeding for weed control in common bean.

Materials and Methods

Description of the study sites

The experiment was conducted in 2012 cropping season at Haramaya (09° 26´ N latitude and 42° 03´ E longitude, with an altitude of 2006 meters above sea level) and Hirna (09° 15´ N latitude and 41° 06´ E longitude, and an altitude of 1870 meters above sea level), Eastern part of Ethiopia. The soil of the experimental sites at Haramaya and Hima had organic matter content of 1.0% and 1.4% (low), total nitrogen content of 0.17% and 0.22% (Moderate), available phosphorus content of 8.72 mg kg $soil^{-1}$ (low) and 32 mg kg $soil^{-1}$ (very high), pH of 8.13 (strongly alkaline) and 6.79 (neutral) and a texture described as sandy loam and clay texture respectively (Cottenie, 1980; Tekalign, 1991; Bethelhem, 2012). The total rainfall during the cropping season (July-October) was 474 and 548 mm, a mean minimum and maximum temperatures of 12°C, 13°C and 24°C and 27°C respectively at Haramaya and Hirna.

Treatments and experimental design

The experiment comprised of 12 treatments *viz*. preemergence s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}), pendimethalin (1.0, 1.25 and 1.5 kg ha^{-1}), low rate of herbicides (1.0 kg ha^{-1} each) supplemented with hand weeding four weeks after emergence (WAE), one hand weeding two WAE, two hand weeding at two and four WAE, weed free, and weedy check. All treatments were laid out in randomized complete block design with three replications.

Management of the experiment

The experimental fields was ploughed and to fine tilth. The plot size used was a 3.2 m x 2.4 m (7.68 m^2) with an inter-row and intra-row spacing of 40 cm and 10 cm, respectively. The export type common bean variety 'Awash Melka' was planted on 13th at Hima and 18th at Haramaya in July 2012. Di-ammonium phosphate fertilizer was applied in drilled furrows at the recommended rate of 100 kg ha^{-1} at planting (Mandefro *et al.*, 2009). The herbicides application was as per the treatment in the assigned plots one day after planting, using a knapsack sprayer fitted with a flat-fan nozzle. Herbicide spray volume with water was 500 l ha^{-1}. The net harvestable area was 2.4 m x 1.6 m (3.84 m^2). Harvesting was done manually at harvest maturity on the 28th October 2012 and 6th November 2012 at both Hirna and Haramaya, respectively from a net harvestable area of 3.84 m^2.

Data collection

The weed flora present in the experimental fields were recorded from weedy check plots just before crop flowering by placing a 0.25 m × 0.25 m quadrat randomly at two spots in each replication and converted into m^{-2}. The species identified were classified according to families with the aid of flora books (Stroud and Parker, 1989; Melaku, 2008). The relative density (RD) of weed species was calculated as;

$$\mathrm{RD} = \left(\frac{\text{Number of individual weed species}}{\text{Total number of weed species}}\right) \times 100$$

Weeds were collected from each plot 15 days before harvest using a quadrat (0.25 m × 0.25 m) thrown randomly at two places, to determine weed density. From the above thrown quadrate the weeds were also cut near to the ground and after three days of sun drying, the samples were oven dried at 65^{o}C to a constant weight to determine aboveground weed 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 as the number of days from planting to when 90% of the 10 pre tagged plant leaves showed yellow color and the pods had turned yellow. Plant height (cm) was measured from the base of plant to the tip of main stem at harvest. The number of pods/plant, number of seeds per pod, and hundred seed weight were all carried after harvesting from 10 randomly selected plants. 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}. Grain yield (kg) was recorded from each net plot area. The moisture content was determined for each treatment and the grain yield was adjusted to 10.5%.
Harvest index (%) was calculated as:

$$\text{Harvest index (\%)} = \left(\frac{\text{Grain yield kg ha}^{-1}}{\text{Aboveground dry biomass kg ha}^{-1}}\right) \times 100$$

Statistical Analysis
Weed density and dry weight were subjected to Bartlett (1936) square root transformation $\sqrt{x+0.5}$ where x is the original value to ensure normality of data before analysis.

The data were subjected to analysis of variance (GLM procedure) using SAS software program version 9.1 (SAS Institute, 2003). Homogeneity of variances was evaluated using the F-test as described by Gomez and Gomez (1984). Where the F-test showed homogeneity of the variances of the two locations, a combined analysis was used. Least significant difference (LSD) test at 5% probability level was employed to separate treatment means whenever a significant treatment difference exists.

Partial budget analysis

The partial budget analysis as described by CIMMYT (1988) was adopted to determine the economic feasibility of weed management practices. Economic analysis was done using the prevailing market prices for inputs at planting and for product 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 represent the difference between the experimental yield and the yield expected by farmers using the same weed management practices. The field price of common bean was calculated as taking into consideration the costs of harvesting, threshing, winnowing, bagging and transportation. The total cost includes the cost of herbicides, their application and labour cost

where hand weeding involved. The net benefit was calculated as the difference between the gross field benefit (ETB ha^{-1}) and the total costs (ETB ha^{-1}) that varied.

Results and Discussion

Weed flora in the experimental fields

The weed flora in the experimental fields consisted of broadleaved and sedge with relative densities of 85.7 and 14.3% at Haramaya, and 70.0 and 30.0%, at Hirna, respectively (Table 1). At Haramaya, nine weed species belonging to nine families were found to infest the experimental plot, while only six species were recorded at Hirna distributed in six families. The reason for more specie occurrence at Haramaya could be attributed to difference in soil type, previous crop, and more rainfall relative to Hirna at early stage of 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/crop management factors that influence the species distribution.

Table 1. Weed specie distribution, density and relative density in common bean fields at Haramaya and Hirna in 2012

		Haramaya		Hirna	
Weed species	Family	Weeds (m^{-2})	Relative density	Weeds (m^{-2})	Relative density (%)
Broadleaved					
Amaranthus dubius Thell.	Amaranthaceae	16	3.6	48	16.3
Argemone ochroleuca L.	Papaveraceae	-	-	16	5.4
Commelina benghalensis L.	Commelinaceae	32	7.2	36	12.2
Convolvulus arvensis L.	Convolvulaceae	36	8.0		-
Datura stramonium L.	Solanaceae	32	7.1	-	-
Equisetum arvense L.	Equisetaceae	32	7.1	-	-
Erucastrum arabicum Fisch. & Mey.	Brassicaceae	64	14.3	-	-
Galinsoga parviflora Cav.	Asteraceae	120	26.8	-	-
Parthenium hysterophorus L.	Asteraceae	-	-	106	36.1
Plantago lanceolata L.	Plantaginaceae	52	11.6	-	-
Total			85.7		70.0
Sedge					
Cyperus rotundus L.	Cyperaceae	64	14.3	88	30.0

The dominant weed species at Haramaya and Hirna were *G. parviflora* (26.8%) and *P. hysterophorus* (36.1%), respectively. The maximum weed densities recorded was 120 and 106 weeds m^{-2} at Haramaya and Hirna, respectively.

Weed density and dry weight

The weed density and dry weight were found to have been significantly (P<0.01) affected by the interaction of weed management practices with sites. The lowest weed density (2.4 m^{-2}) was recorded at Hirna with the application of s-metolachlor at 2.0 kg ha^{-1} and significant when compared to the other herbicides rates, lower dose herbicides supplemented with hand weeding and hand weeding at both sites (Table 2).

Application of s-metolachlor at 1.0 kg ha^{-1} + one hand weeding at four WAE gave the lowest weed dry weight (4.9 g m^{-2}) which was statistically at par with s-metolachlor at 2.0 kg ha^{-1} and pendimethalin at 1.0 kg ha^{-1} + one hand weeding at four WAE at Haramaya (Table 2). S- metolachlor at 2.0 kg ha^{-1} at Hirna and s-metolachlor at 1.0 kg ha^{-1} + one hand weeding four WAE at Haramaya reduced the weed density and dry weight by 85.7 and 82.0%, respectively as compared to the weedy check at the respective sites. The better performance of s-metolachlor in reducing weed dry biomass as compared to pendimethalin, metribuzin and isoproturon in pea has also been reported by Sajid *et al*. (2012).

Days to flowering and physiological maturity

Results as presented in Table 3 showed that sites had significant (P<0.01) influence on days to flowering and physiological maturity of common bean while weed management practices had significant (P=0.04) effect on days to flowering but not on days to physiological maturity.

Common bean plants at Hirna attained flowering 6 days earlier when compared with Haramaya. This might be due to the difference in rainfall and temperature at the sites. However, days to flowering under weed free check was statistically at par with pendimethalin at 1.5 kg ha^{-1}, s-metolachlor at 1.5 kg and 2.0 kg ha^{-1} (Table 3).

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. Similar to the days to flowering, the physiological maturity of the crop was also delayed by 7 days at Haramaya than at Hirna. The reason for delayed maturity could be due to higher weed density and relatively lower temperature and total rainfall at Haramaya. Moriondo and Bindi (2007) reported that increasing temperature results in early development of crops and a reduction in length of growing season.

Table 2. Interaction effects of weed management practices and sites on weed density and dry biomass in 2012.

Weed management practices	Weed density (m^{-2})		Weed dry weight (g m^{-2})	
	Haramaya	Hirna	Haramaya	Hirna
Pendimethalin 1.0 kg ha^{-1}	14.2^{c} (202.7)	13.0^{cd} (170.7)	18.4^{cd} (359.3)	21.0^{bc} (448.0)
Pendimethalin 1.25 kg ha^{-1}	11.0^{ef} (120.0)	9.7^{fg} (93.3)	17.9^{cd} (323.7)	17.2^{d} (297.0)
Pendimethalin 1.5 kg ha^{-1}	8.9^{ghi} (79.7)	7.7^{hij} (58.7)	13.6^{ef} (191.0)	12.6^{fg} (161.3)
S-metolachlor 1.0 kg ha^{-1}	7.6^{ij} (59.3)	7.5^{ij} (56.0)	8.8^{hi} (82.3)	17.4^{d} (301.7)
S-metolachlor 1.5 kg ha^{-1}	5.5^{kl} (30.0)	4.9^{l} (24.0)	9.0^{hi} (82.1)	17.0^{de} (291.2)
S-metolachlor 2.0 kg ha^{-1}	4.9^{l} (24.0)	2.4^{m} (5.3)	6.9^{ij} (47.3)	11.0^{fgh} (133.1)
Pendimethalin 1.0 kg ha^{-1} + one hand weeding 4 WAE	7.0^{jk} (48.0)	9.9^{fg} (98.0)	6.5^{ij} (42.3)	17.1^{d} (292.0)
S-metolachlor 1.0 kg ha^{-1} + one hand weeding 4 WAE	5.4^{kl} (29.3)	8.6^{ghi} (74.7)	4.9^{j} (24.3)	10.5^{fgh} (108.9)
One hand weeding at 2 WAE	9.3^{gh} (85.3)	11.5^{de} (133.3)	9.1^{hi} (82.6)	22.6^{b} (512.0)
Two hand weeding at 2 and 4 WAE	7.7^{hij} (61.3)	8.8^{ghi} (77.7)	8.7^{hi} (75.8)	9.4^{ghi} (88.8)
Weed free check	0.7^{n} (0.0	0.7^{n} (0.0)	0.7^{k} (0.0)	0.7^{k} (0.0)
Weedy check	20.0^{a} (400.0)	16.8^{b} (285.3)	27.2^{a} (761.3)	22.8^{b} (517.6)
LSD$_{(5\%)}$	1.6		3.5	
CV (%)	11.4		16.4	

WAE = Weeks after emergence; Figures in parentheses are the original; Means followed by the same letters within each column and rows for the same parameters are not significantly different; LSD = Least significant difference; CV = Coefficient of **v**ariation.

Table 3. Effect of Sites and weed management practices on crop phenology and plant height in 2012.

Factors	Days to Flowering	Days to physiological maturity	Plant height (cm)
Sites			
Haramaya	61^{a}	100^{a}	64.0^{b}
Hirna	55^{b}	93^{b}	96.1^{a}
LSD$_{(5\%)}$	1.4	1.3	4.7
Weed management practices			
Pendimethalin 1.0 kg ha^{-1}	60^{ab}	97	76.5
Pendimethalin1.25 kg ha^{-1}	58^{abc}	96	75.7
Pendimethalin 1.5 kg ha^{-1}	56^{cd}	96	73.2
S-metolachlor 1.0 kg ha^{-1}	58^{abc}	97	86.8
S-metolachlor 1.5 kg ha^{-1}	57^{a-d}	98	81.9
S-metolachlor 2.0 kg ha^{-1}	57^{a-d}	97	74.1
Pendimethalin 1.0 kg ha^{-1}+ one hand weeding 4 WAE	58^{abc}	97	83.6
S-metolachlor 1.0 kg ha^{-1}+ one hand weeding 4 WAE	58^{abc}	98	82.1
One hand weeding at 2 WAE	58^{abc}	95	80.1
Two hand weeding at 2 and 4 WAE	58^{abc}	96	79.7
Weed free check	54^{d}	95	78.2
Weedy check	60^{a}	98	88.7
LSD$_{(5\%)}$	3.4	NS	NS
CV (%)	5.0	2.9	12.3

WAE = Weeks after crop emergence; LSD = Least significant difference; CV = Coefficient of **v**ariation; NS = not significant Means followed by the same letters within column are not significantly different.

Plant height

Sites significantly (P<0.01) influenced plant height while the weed management practices and its interaction with location did not significantly affect plant height. Common bean plants at Hirna were taller by 50.2% than at Haramaya (Table 3). The taller height attained by the plants at Hirna could be due to relatively higher seasonal rainfall and temperature at Hirna than at Haramaya. In addition, the soil fertility condition at Hirna with organic matter content of 1.4%, total nitrogen content of 0.22%, available phosphorus content of 32 mg kg soil^{-1} was better than Haramaya which had organic matter content of 1.0%, total nitrogen content of 0.17%, available phosphorus content of 8.72 mg kg soil^{-1} (Bethelhem, 2012). More sunlight penetration to the crop plants also made photosynthates available, however, no significant difference in plant height was found among the weed management practices despite a great variation in weed density and dry weight.

Yield components of common bean

Hundred seed weight

Sites and weed management practices significantly (P<0.01 and P=0.04) influenced hundred seed weight, respectively. Hundred seed weight (18.1g) of common bean at Hirna was significantly higher than at Haramaya (17.6g) (Table 4). The relatively higher rainfall, temperature and soil conditions at Hirna during the cropping season might have helped common bean plants to produce well filled and heavier seeds.

Table 4. Effect of Site and Weed management practices on hundred seed weight, grain yield and harvest index of common bean in 2012.

Factors	Hundred seed weight (g)	Grain yield (kg ha^{-1})	Harvest index (%)
Sites			
Haramaya	17.6^{b}	2263^{b}	38^{a}
Hirna	18.1^{a}	2776^{a}	32^{b}
LSD $_{(5\%)}$	0.3	182.4	3.1
Weed management practices			
Pendimethalin 1.0 kg ha^{-1}	18.1^{ab}	1758^{gh}	26
Pendimethalin1.25 kg ha^{-1}	17.9^{ab}	2149^{fg}	35
Pendimethalin 1.5 kg ha^{-1}	18.2^{ab}	2314^{ef}	38
S-metolachlor 1.0 kg ha^{-1}	17.8^{ab}	2524^{cf}	36
S-metolachlor 1.5 kg ha^{-1}	17.8^{ab}	2654^{be}	36
S-metolachlor 2.0 kg ha^{-1}	17.9^{ab}	2832^{ad}	35
Pendimethalin 1.0 kg ha^{-1}+ one hand weeding 4 WAE	18.0^{ab}	3021^{ab}	38
S-metolachlor 1.0 kg ha^{-1}+ one hand weeding4 WAE	17.7^{bc}	3024^{ab}	36
One hand weeding at 2 WAE	17.4^{bc}	2399^{def}	35
Two hand weeding at 2 and 4 WAE	18.1^{ab}	2870^{abc}	36
Weed free check	18.6^{a}	3198^{a}	36
Weedy check	16.9^{c}	1493^{h}	32
LSD $_{(5\%)}$	0.8	446.8	NS
CV (%)	4.0	15.2	19.0

WAE = Weeks after emergence; LSD = Least significant difference; CV = Coefficient of variation; NS = not significant; Means followed by the same letters within each column are not significantly different

Weed free check gave the highest hundred seed weight (18.6 g) but did not vary significantly with the pendimethalin , s-metolachlor as well as with pendimethalin at 1.0 kg ha^{-1} + one hand weeding four WAE, and two hand weeding at two and four WAE (Table 4). Contrary to this study, Meseret et al. (2008) reported no significant difference in grain weight due to weed management practices in common bean.

Weedy check gave the lowest hundred seed weight (16.9 g) that did not vary significantly with the s-metolachlor at 1.0 kg ha^{-1} + one hand weeding four WAE and one hand weeding at two WAE. However, with the exception of weed free check, s-metolachlor at 1.0 kg ha^{-1} + one hand weeding four WAE did not vary significantly with the rest of the weed management practices. This is consistent with Madukwe et al. (2012) who stated that cowpea plants in unweeded plots gave the lowest hundred seed weight.

Number of pods per plant

The interaction of weed management practices with sites significantly ($P<0.01$) influenced the number of pods per plant. The highest number of pods per plant (26.9) was obtained from the application of pendimethalin at 1.25 kg ha^{-1} at Hirna; however, this value was at par with pendimethalin at 1.5 kg ha^{-1}, s-metolachlor at 2.0 kg ha^{-1}, pendimethalin at 1.0 kg ha^{-1} + one hand weeding at four WAE, and two hand weedings at two and four WAE at Hirna as well as weed free check at both sites (Table 5). In these weed management practices the increased number of pods per plant could be due to the reduced weed competition that made growth resources more accessible for individual plant. This might have resulted in higher net assimilation rate thus retaining more flowers and 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 lowest number of pods per plant (12.4) was from weedy check at Hirna which was significantly lower than all the treatments except pendimethalin at 1.0 kg ha^{-1} at both sites. On top of this pendimethalin at 1.25 kg ha^{-1}, pendimethalin at 1.5 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}, s-metolachlor at 2.0 kg ha^{-1}, two hand weedings at 2 and 4 WAE and weedy check at Haramaya (Table 5).

The long-season weed interference might have also resulted in shade effect that reduced the irradiance predominantly in the photosynthetically active region of the spectrum as the irradiance is a major ecological factor that influences plant growth (Hadi, 2006).

Table 5. Interaction effects of weed control practices and sites on number of pods per plant and biomass of common bean in 2012.

Weed management practices	Number of pods plant^{-1}		Aboveground dry biomass (kg ha^{-1})	
	Haramaya	Hirna	Haramaya	Hirna
Pendimethalin 1.0 kg ha^{-1}	15.7^{g-j}	12.9^{j}	6250^{efg}	7813^{cde}
Pendimethalin 1.25 kg ha^{-1}	15.0^{hij}	26.9^{a}	5382^{fg}	7986^{cde}
Pendimethalin 1.5 kg ha^{-1}	15.8^{g-j}	23.4^{a-d}	6250^{efg}	6076^{efg}
S-metolachlor 1.0 kg ha^{-1}	16.4^{f-j}	20.2^{b-h}	5729^{fg}	8681^{bcd}
S-metolachlor 1.5 kg ha^{-1}	19.3^{c-h}	20.8^{b-g}	6250^{efg}	9201^{bc}
S-metolachlor 2.0 kg ha^{-1}	15.1^{hij}	21.6^{a-f}	6424^{efg}	10243^{ab}
Pendimethalin 1.0 kg ha^{-1}+ one hand weeding 4 WAE	20.8^{b-g}	21.7^{a-e}	6076^{efg}	10417^{ab}
S-metolachlor 1.0 kg ha^{-1}+ one hand weeding 4 WAE	18.2^{d-i}	19.3^{c-h}	6771^{def}	10590^{ab}
One hand weeding at 2 WAE	19.2^{c-h}	19.1^{d-i}	6076^{efg}	7986^{cde}
Two hand weeding at 2 and 4 WAE	16.7^{e-j}	22.8^{a-d}	6250^{efg}	10069^{ab}
Weed free check	25.4^{ab}	24.4^{abc}	6771^{def}	11979^{a}
Weedy check	15.7^{g-j}	12.4^{j}	4514^{g}	5035^{fg}
LSD $_{(5\%)}$	5.3		1966.8	
CV (%)	16.9		16.0	

WAE= Weeks after crop emergence; LSD= Least significant difference; CV= Coefficient of **v**ariation; NS=not significant; Means followed by the same letters within each column are not significantly different.

Aboveground dry biomass

The interaction of weed management practices and sites significantly (P<0.01) influenced aboveground dry biomass. The highest aboveground dry biomass (11979 kg ha^{-1}) was from weed free check at Hirna; however, this was at par with s-metolachlor at 2.0 kg ha^{-1}, pendimethalin and s-metolachlor each at 1.0 kg ha^{-1} and supplemented with one hand weeding, and two hand weeding at 2 and 4 WAE at Hirna (Table 5). On the other hand, the lowest aboveground dry biomass (4514 kg ha^{-1}) was recorded from weedy check at Haramaya which was not significantly different from all but s-metolachlor at 1.0 kg ha^{-1} + one hand weeding four WAE and weed free check at Haramaya. On top of this, weedy check and pendimethalin at 1.5 kg ha^{-1} at Hirna were also not significantly different from this value. The rest of the weed management practices at Hirna had significantly higher aboveground dry biomass than the lowest value. In line with this result, Davier and Gardiner (1985) 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.

In general, plants at Hirna accumulated more aboveground dry biomass yield than at Haramaya, which could partially be ascribed to height advantage (Table 3), hundred seed weight (Table 4) and pods plant^{-1} at Hirna (Table 5). Though, variable results of weed management practices on plant height, number of pods plant^{-1}, seeds pod^{-1} and hundred seed weight were obtained but their cumulative effect might have also influenced the aboveground dry biomass yield.

Grain yield and harvest index

Sites and weed management practices significantly (P<0.01) influenced grain yield. Grain yield at Hirna was significantly higher (22.7%) than at Haramaya (Table 4). The increased yield at Hirna could be due to more conducive environmental conditions at Hirna which might have favourably influenced plant growth, development and reproduction.

Weed free check gave the highest grain yield (3198 kg ha^{-1}) that did not vary significantly with s-metolachlor at 2.0 kg ha^{-1}, pendimethalin at 1.0 kg ha^{-1} + one hand weeding, and two hand weeding. The possible reason for the highest grain yield in these treatments could be better control of weeds. Therefore, less competition offered by weeds resulted in better nodule development, which might have fixed more atmospheric nitrogen and higher hundred seed weight resulting in higher yield. Weedy check gave the lowest grain yield (1493 kg ha^{-1}) which did not significantly vary with pendimethalin at 1.0 kg ha^{-1}. The lowest grain yield in these treatments might be due to competition for resources as a result of high weed density and dry weight (Table 2).

The application of lowest dose of herbicides pendimethalin and s-metolachlor each at 1.0 kg ha^{-1} superimposed with one hand weeding four WAE gave significantly highest grain yield compared to different rates of herbicides, except s-metolachlor at 1.5 and 2.0 kg ha^{-1}. This might be due to application of herbicide reduced competition from weeds till hand weeding and later on weeds were controlled with hand weeding and hoeing at four WAE, which could have resulted in initial advantage in favour of the crop. Similarly, Dawit et al. (2011) reported that combined use of pendimethalin and s-metolachlor (1 kg ha^{-1}) with hand weeding 35 days after sowing increased the yield of common bean.

Sites significantly (P<0.01) influenced harvest index, whereas the weed management practices did not significantly influence harvest index. The harvest index at Hirna was significantly higher (38%) than at Haramaya (32%) (Table 4). This could be due to better soil fertility and relatively higher rainfall and temperature during the cropping season at Hirna compared to Haramaya. These conditions could help common bean at Hirna to accumulate more dry matter and partitioning of assimilates to the grain.

Economic feasibility of weed management practices in common bean

Weed management practices significantly ($P<0.01$) influenced grain yield. The result of the partial budget analysis and the data used for the analysis is tabulated (Table 6). The economic analysis revealed that the highest net benefit of ETB 19,671 was obtained from application of s-metolachlor at 1.0 kg ha^{-1} + one hand weeding 4 WAE. The benefit gained from this treatment was 92.6% greater than from the value obtained from the weedy check. Similar to this result, Dawit et al. (2011) reported that the application of s-metolachlor 1.0 kg ha^{-1} + one hand weeding 35 days after sowing gave the highest net benefit in common bean.

The highest net benefits from the abovementioned weed management practice could be attributed to high yield and low cost of herbicide compared to the labour cost. Thus, from the economic point of view, it was obvious that lower rate of s-metolachlor at 1.0 kg ha^{-1} + one hand weeding 4 WAE was more economical than the rest of the weed management practices.

Table 7. Partial budget analysis for weed management practices of common bean in 2012

Weed management practices	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross benefit (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})
Pendimethalin 1.0 kg ha^{-1}	1758	1582	12023	870	11153
Pendimethalin1.25 kg ha^{-1}	2149	1934	14698	1055	13643
Pendimethalin 1.5 kg ha^{-1}	2314	2083	15831	1241	14590
S-metolachlor 1.0 kg ha^{-1}	2524	2272	17267	336	16931
S-metolachlor 1.5 kg ha^{-1}	2654	2389	18156	440	17716
S-metolachlor 2.0 kg ha^{-1}	2832	2549	19372	544	18828
Pendimethalin 1.0 kg ha^{-1} + one hand weeding 4 WAE	3021	2719	20664	1550	19114
S-metolachlor 1.0 kg ha^{-1} + one hand weeding 4 WAE	3024	2722	20687	1016	19671
One hand weeding at 2 WAE	2399	2159	16408	1700	14708
Two hand weeding at 2 and 4 WAE	2870	2583	19631	2380	17251
Weedy check	1493	1344	10214	0	10214

ETB = Ethiopian Birr; WAE = Weeks after crop emergence; Cost of pendimethalin and s-metolachlor 742 and ETB 208 kg^{-1}, respectively; Spraying ETB 128 ha^{-1}; Cost of labour ETB 43 man day^{-1}; Sale price of common bean ETB 9 kg^{-1}; Field price of common bean ETB 7.60 kg^{-1}; Cost of harvesting, Threshing and winnowing ETB 130 100 kg^{-1}; Packing and material cost ETB 4 100 kg^{-1} and Transportation ETB 6 100 kg^{-1}; ETB = 0.0481 USD (August 12, 2015).

Conclusion

The use of lowest rate of herbicide s-metolachlor 1.0 kg ha^{-1} supplemented with one hand weeding four weeks after crop emergence to control weeds increased the yield and yield components as well as economic benefit of common bean production in eastern Ethiopia. The benefit gained from s-metolachlor 1.0 kg ha^{-1} + one hand weeding four weeks after crop emergence was 92.6% greater than from the value obtained from the weedy check.

Acknowledgement

Authors are grateful to the Swedish Agency for Research Co-operation with Developing Countries (SIDA/SAREC) for providing the fund and Haramaya University for the provision of research facility.

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