ORIGINAL ARTICLE

Management of Weeds in Common Bean (*Phaseolus vulgaris* L.) through Herbicide Combinations in Eastern Ethiopia

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ABSTRACT

Weeds cause significant yield and quality loss in common bean. Therefore, the effects of low dose herbicide combinations were evaluated for broad spectrum weed management in common bean at Haramaya and Hirna, eastern Ethiopia in 2013 main cropping season. The study comprised 14 treatments: s-metolachlor and pendimethalin each at 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding at 4 weeks after crop emergence (WAE), combinations of s-metolachlor + pendimethalin (1.0 + 1.0, 0.75 + 1.0, 1.0 + 0.75, 0.75 + 0.75, 0.5 + 1.0, 1.0 + 0.5, 0.5 + 0.5, 0.5 + 0.75 and 0.75 + 0.5 kg ha^{-1}), one hand hoeing and weeding 2 WAE, weed-free and weedy check arranged in a randomized complete block design with three replications. Weed flora in the experimental fields consisted of broadleaved and sedge with the respective relative densities of 95.6 and 4.4% at Haramaya, and 23.4 and 76.6% at Hirna. S-metolachlor at 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WAE significantly reduced the weed dry weight by 50.0% compared to the weedy check plots. S-metolachlor 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WAE had significantly higher number of pods plant^{-1}, number of seeds pod^{-1}, hundred seed weight, grain yield (4045.3 kg ha^{-1}) and aboveground dry biomass than the weedy check plots. Significantly higher grain yield (3878.6 kg ha^{-1}) was recorded at Hirna than at Haramaya. The highest net benefit of ETB 33601 ha^{-1} was obtained by application of s-metolachlor at 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE.

Keywords: Hand weeding**;** Low herbicide dose; Pendimethalin; S-metolachlor

INTRODUCTION

Among the pulse crops, common bean (*Phaseolus vulgaris* L.) is the second in area of production in the country and the first in production and productivity in east and west Hararghe zones (CSA, 2015). It is an important source of protein, source of cash, and emergency crop. The total production, household consumption and sale of common bean (*Phaseolus vulgaris* L.) in 2014/15 cropping season in Ethiopia were 343448 tons, 67% and 20%,respectively (CSA, 2015). The corresponding values in East Hararghe Zone were 8849 t, 89% and 3%, while in West Hararghe Zone these values were 3404 t, 77% and 9%. The household consumption of common bean is the highest of all the rest of the pulse crops in both Zones.

Common bean, being a weak competitor to weeds, gets infested with a variety of weeds and subjected to heavy weed competition, which often inflicts huge losses ranging from 58 to 98% (Ahmadi *et al*., 2007; Dawit *et al*., 2011; Mengesha *et al*., 2013). Weeds also interfere with harvest operations and may stain common bean, resulting in reduced market value (Urwin *et al*., 1999). Therefore, weed management is very important for profitable and sustainable common bean production. Identification of weed management strategies that provide consistent effective broad spectrum control needed to make common bean growers more competitive in the local and world markets.

Chemical weed management is a better supplement to conventional methods and a vital part of the modern integrated crop production. Use of herbicides to manage weeds is an alternative option to hand weeding. The inability to manage weeds by hand, declining labour availability and the drudgery involved in weeding in wet and/or dry conditions, will encourage and increasingly justify the use of herbicides (Mashingaidze *et al*., 2003). Herbicides offer substantial increase in crop yield through effective weed suppression (Kahramanoglu and Uygur, 2010). However, overuse and/or misuse of synthetic herbicides has resulted in problems, like environmental pollution, soil and water contamination, development of resistance among weed biotypes and threats to human health (Snelder *et al.*, 2008). On the contrary, herbicides applied at lower doses will have a fit into specific situations as they might allow increased profits to be realized by growers, reduce potential injury to current and succeeding susceptible crops, and minimize risk to the environment (Blackshaw *et al*., 2006). Sustainable weed management is irretrievably linked to the development of competitive cropping systems that reduce weed populations over time.

Most of the presently available herbicides provide only narrow spectrum weed suppression. Many of them have activity only on annual species, while a few are only effective against perennials. One of the causes of herbicide resistance in weeds is the continuous application of the same herbicide or herbicides of the same mechanism of action year after year in the same field (Duke, 1996).

Applying two or more herbicides simultaneously, either using prepackages mixtures or by tank mixing different herbicide products before the application, is a very common approach in intensive agriculture (Zhang *et al*., 1995). Interactions in herbicide mixtures can occur prior, during, or after application of the mixture. This means that herbicides may interact physically or chemically in the spray solution or biologically in the plant. Hence, use of two or more different chemicals with different mode of action enhances the efficacy of weed management.

Combination of graminicide herbicides with broadleaved herbicides has been shown to improve the level of weed management in dry bean (*Phaseolus vulgaris* L.) (Blackshaw *et al*., 2000). Similarly, Soltani *et al*. (2007) reported that yield of white bean (*P. vulgaris* L.) was increased when graminicides, such as dimethenamid-p were applied in combination with broadleaved herbicides, such as imazethapyr. Metolachlor tank mixed with either pendimethalin or trifluralin had the widest range of weed management and the highest yields (Stall *et al*., 1989). Soltani and Sikkema (2005) reported that s-metolachlor, a chloroacetamide herbicide, in combination with imazethapyr, an imidazolinon herbicide, could provide suppression of a broad range of grass and broadleaved weeds. Tank mixes of s-metolachlor plus imazethapyr,s-metolachlor plus linuron, and s-metolachlor plus imazethapyr plus linuron all provided an adequate margin of crop safety and excellent management of redroot pigweed, common lambsquarters and green foxtail in kidney bean (*P. vulgaris* L.) (Soltani *et al*., 2014).

Thus, there is a need to compare the effect of mixture of s-metolachlor and pendimethalin in common bean production under eastern Ethiopian conditions. Besides, the efficiency of herbicides and their combination in managing weeds can vary with soil type, temperature and rainfall. Furthermore, there is agricultural investment expansion, particularly for export-oriented pulse crops in the country where the results of this study will have immediate application.

Therefore, the objectives of this study were to assess the effect of herbicide combinations on weed dry weight, yield attributes and yield of common bean, and to determine the economic feasibility of different weed management practices for common bean production.

MATERIALS AND METHODS

Description of the study sites

The experiment was conducted at Haramaya (09° 26′ N latitude, 42° 03′ E longitude, and altitude of 2006 meters above sea level) and Hirna (09° 15′ N latitude, 41° 06′ E longitude, and altitude of 1870 meters above sea level), in eastern Ethiopia, in 2013 main cropping season (July-October). 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 (Bethelhem, 2012). The soil of Hirna had organic matter content of 1.4%, total nitrogen content of 0.22%, available phosphorus content of 32 mg kg soil^{-1}, and pH of 6.79 with clay texture (Bethelhem, 2012).

The total rainfall during the 2013 main cropping season (July-October) was 614 mm and 730 mm at Haramaya and Hirna, respectively. The respective mean minimum and maximum temperatures during the main cropping season were 12 and 23 °C at Haramaya, and 13 and 26 °C at Hirna.

Experimental materials

Export type white coloured common bean variety Awash Melka, which was released by Melkassa Agricultural Research Center in 1998 with maturity period of 95-100 days was used for the experiment. Diammonium phosphate (DAP) (18% N and 46% P_2O_5 ha^{-1}) was used as fertilizer source. The following pre-emergence herbicides were used as treatments in the experiment (Table 1).

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

Treatments and experimental design

The experiment comprised of 14 treatments. These were pendimethalin at 1.0 kg ha^{-1} plus one hand hoeing and weeding at 4 weeks after crop emergence (WAE), s-metolachlor at 1.0 kg ha^{-1} plus one hand hoeing and weeding 4 WAE, tank mix combinations of the respective s-metolachlor + pendimethalin (1.0 + 1.0, 0.75 + 1.0, 1.0 + 0.75, 0.75 + 0.75, 0.5 + 1.0, 1.0 + 0.5, 0.5 + 0.5, 0.5 + 0.75 and 0.75 + 0.5 kg ha^{-1}), one hand hoeing and weeding 2 WAE, weed-free and weedy check. Each treatment was replicated three times in a randomized complete block design.

Experimental procedure and management

The experimental fields were prepared to get fine seedbed. 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 with the net harvestable area of 1.6 m × 2.4 m (3.84 m^2). The common bean was planted at Hirna and Haramaya on 11th and 19th July 2013, respectively. The fertilizer was drilled in furrows at the recommended rate of 100 kg DAP ha^{-1} at planting (Mandefro *et al*., 2009). The herbicides were applied as pre-emergence 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. The hand hoeing and weeding was done as per the treatment. The frequency of weeding in the weed-free plots was based on the appearance of weeds. Harvesting was done manually at harvest maturity at Hirna and Haramaya on 9th and 12th October 2013, respectively. The biomass was sun-dried after harvest for 10 days and threshing and winnowing were done subsequently.

Data Collection and analysis

Data collection

The weed flora present in the experimental fields were recorded from the weedy check plots in each replication by placing a quadrat (0.25 m × 0.25 m) randomly at two spots in each replication just before crop flowering. To determine weed dry weight weeds were collected 15 days before harvest from each plot by using quadrat (0.25 m × 0.25 m) thrown randomly at two places. The weeds at this stage were cut close to the ground, and dried for three days, 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. Weed dry weight was subjected to square root transformation $(\sqrt{x+0.5})$ to ensure normality of data before analysis of variance, where x is the original dry weight. Total number of pods in 10 randomly taken plants in each plot was counted at harvest and expressed as the number of pods per plant. From these pods, the seeds were counted to determine the number of seeds per pod. Hundred seeds were counted from each plot from the bulk seeds, which had known moisture and their weight was recorded and the weight was adjusted at 10.5%. Aboveground dry biomass yield was measured at physiological maturity after cutting 10 randomly sampled plants at ground level and sun dried. Per plant aboveground dry biomass was multiplied with the number of plants in net plot area to calculate total aboveground dry biomass yield that was converted into kilogram per hectare (kg ha^{-1}). Grain yield (kg) was recorded from each net plot area. The moisture content was determined for each plot and the yield was adjusted to 10.5%.

Data analysis

The data were subjected to analysis of variance via GLM procedure using SAS software program version 9.1 (SAS Institute, 2003). Homogeneity of variances was tested 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 locations, combined analysis of variance was used for the two locations. 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 performed to determine the economic feasibility of the weed management practices. Economic analysis was done using the 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. The 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 common bean was calculated as sale price minus the costs of harvesting, threshing, winnowing, bagging and transportation. The total variable cost 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 (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 the respective relative densities of 95.6 and 4.4% at Haramaya, and 23.4 and 76.6% at Hirna (data not shown). Fourteen and five weed species belonging to eight and three families infested the experimental plots at Haramaya and Hirna, respectively.

Weed dry weight (g m^{-2})

Sites and weed management practices significantly ($P < 0.01$) influenced weed dry weight while their interaction had no significant effect (Table 2). The weed dry weight at Haramaya was significantly higher by 21.4% than at Hirna (Table 2). The higher weed dry weight recorded at Haramaya could be due to significantly shorter height of common bean and relatively more weed species occurrence at the site than at Hirna. The taller crop plant height at Hirna might have resulted in shading effect that reduced the irradiance reaching the weeds and hence resulting in reduced dry matter production by the weeds. Application of s-metolachlor at 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WAE was at par with pendimethalin at 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE, s-metolachlor at 1.0 kg ha^{-1} + pendimethalin at 1.0 kg ha^{-1}, and one hand hoeing and weeding 2 WAE.

Table 2. Weed dry weight and number of pods per plant of common bean as influenced by the main effects of sites and weed management practices

Factors	Weed dry weight (g m^{-2})	Number of pods per plant
Sites		
Haramaya	14.2^{a} (222.3)	18.9^{b}
Hirna	11.7^{b} (158.0)	22.1^{a}
Significance	**	**
LSD (5%)	0.9	1.4
Weed management practices		
S-metolachlor 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE	10.1^{g} (103.5)	23.3^{ab}
Pendimethalin 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE	10.3^{g} (108.7)	22.4^{abc}
S-metolachlor 1.0 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	11.2^{fg} (129.6)	22.2$^{a\text{-}d}$
S-metolachlor 0.75 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	13.6^{cde} (191.9)	20.6$^{b\text{-}e}$
S-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	12.9^{def} (167.2)	20.8$^{b\text{-}e}$
S-metolachlor 0.75 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	14.5$^{b\text{-}e}$ (214.5)	20.1$^{b\text{-}e}$
S-metolachlor 0.5 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	14.6^{bcd} (219.2)	19.5^{cde}
S-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	13.8^{cde} (197.2)	20.2$^{b\text{-}e}$
S-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	16.5^{b} (279.9)	18.3^{ef}
S-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	15.5^{bc} (244.5)	18.5^{def}
S-metolachlor 0.75 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	14.9^{bcd} (229.6)	19.1$^{c\text{-}f}$
One hand hoeing and weeding 2 WAE	12.3^{efg} (154.7)	21.3$^{b\text{-}e}$
Weed-free check	0.7^{h} (0.0)	25.3^{a}
Weedy check	20.2^{a} (422.1)	15.5^{f}
Significance	**	**
LSD (5%)	2.3	3.8
CV (%)	15.1	16.0

WAE = weeks after crop emergence; Values outside parentheses are the square root transformed and in parentheses are the original values; Means followed by the same letters within each column are not significantly different; *, ** significant at P = 0.05 and 0.01, respectively; LSD = least significant difference; CV = coefficient of **v**ariation;

The reduction in weed dry weight due to these treatments ranged from 39.1 to 50.0% over the weedy check (Table 2). The significantly lower weed dry weight in these weed management practices could be due to the application of higher doses of herbicides in combination, low dose of herbicides supplemented with hand hoeing and weeding practice that uprooted the emerged weeds and finally the crop canopy, which could suppress the weed growth. In line with this result, application ofcombination of the herbicides atrazine and pendimethalin (0.50 + 0.25 kg ha^{-1}) was found to be effective in reducing weed growth and infestation, which resulted in low dry weight of weeds in maize (Patel *et al*., 2006).

Number of pods per plant of common bean

Number of pods per plant was significantly ($P < 0.01$) affected by sites and weed management practices (Table 2). Significantly higher number of pods per plant (16.9%) was obtained at Hirna than at Haramaya. This might be due to significantly lower weed dry weight at Hirna, consequently lesser weed interference than at Haramaya (Table 2). Furthermore, the favourable growth condition due to relatively higher rainfall and temperature at Hirna might have contributed to high number of pods per plant.

Plants, kept weed-free throughout the season, had the highest number of pods per plant (25.3). This might be due to the absence of competition from weeds. In agreement with this, Jain (2000) reported the highest number of pods per plant in weed-free treatment in soybean. Similarly, Peer *et al*. (2013) reported that weed-free treatment produced 58.4% more pods than weedy check in soybean. The number of pods plant^{-1} obtained from weed-free plots was statistically at par with s-metolachlor at 1.0 and pendimethalin at 1.0 kg ha^{-1} each supplemented with one hand hoeing and weeding 4 WAE as well as combination of s-metolachlor and pendimethalin each at 1.0 kg ha^{-1}. This might be due to decreased weed competition as these treatments had relatively lower weed dry weight than the rest of the herbicidal treatments (Table 2). S-metolachlor at 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WAE significantly increased the number of pods plant^{-1} by 50.3% over the weedy check. In line with this result, Abdellatif (2008) reported that the integrated use of herbicides with hand weeding might have helped in producing more vigorous leaves under low weed infestation that improved the photosynthetic efficiency of the faba bean (*Vicia faba* L.) and supported a large number of pods. Similarly, Veeramani *et al*. (2001) reported more pods with integrated use of herbicides with hand weeding in soybean than herbicides application alone. Likewise, Peer *et al*. (2013) also reported that fluchloralin and pendimethalin at lower rates (1.0 kg ha^{-1} each) in combination with hand weeding resulted in higher number of pods plant^{-1} which was at par with weed-free in soybean.

On the other hand, the weedy check plots had the lowest number of pods plant^{-1}, which was statistically in parity with s-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}, s-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1} and s-metolachlor 0.75 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}. Similarly, the unweeded check plots gave the lowest number of pods per plant in soybean (Peer *et al*., 2013). The lower number of pods plant $^{-1}$ in plots treated with low dose herbicide mixtures might be the consequence of translocation and availability of low amount of herbicide at the active site of action in weeds, thus enhanced weed interference with crop for growth resources.

Number of seeds per pod of common bean

Sites and weed management practices significantly affected the number of seeds pod^{-1} (Table 3). Unlike number of pods plant^{-1}, number of seeds pod^{-1} was significantly higher by 6.3% at Haramaya than at Hirna. The reason could be that there was lower number of pods per plant at Haramaya than at Hirna, thus the competition within the pods for growth resources might be low resulting in more number of seeds per pod.

Plants, which were kept weed-free throughout the season, had the highest number of seeds pod^{-1} (7.1). However, it did not differ significantly from the treatment with s-metolachlor and pendimethalin at 1.0 kg ha^{-1}, each supplemented with one hand hoeing and weeding 4 WAE, and s-metolachlor at 1.0 kg ha^{-1} + pendimethalin at 1.0 kg ha^{-1}, s-metolachlor at 0.75 kg ha^{-1} + pendimethalin at 1.0 kg ha^{-1} and one hand hoeing and weeding 2 WAE. This could be due to reduced weed dry weight in these treatments (Table 2). The weed dry weight which indicates the level of competition was reduced due to early management of weeds by herbicides applied alone or in combinations, and supplemented with hand weeding. The later emerged weeds were in competitive disadvantage and thus, might have failed to reduce number of seeds per pod significantly. In agreement with this result, Peer *et al*. (2013) reported significantly higher number of seeds pod^{-1} in weed-free treatment in soybean. The comparatively best weed management practice, next to weed-free treatment, was application of s-metolachlor 1.0 kg ha^{-1} supplemented with hand hoeing and weeding 4 WAE, which gave 14.8% more number of seeds pod^{-1} than the weedy check plots.

Plants, which were not weeded throughout the season, had the lowest number of seeds pod^{-1} (6.1) (Table 3) of all the treatments. However, this was statistically in parity with all weed management practices, except treatment with s-metolachlor and pendimethalin at 1.0 kg ha^{-1} each supplemented with hand hoeing and weeding 4 WAE, s-metolachlor at 1.0 kg ha^{-1} + pendimethalin at 1.0 kg ha^{-1}, s-metolachlor at 0.75 kg ha^{-1} + pendimethalin at 1.0 kg ha^{-1}, hand hoeing and weeding 2 WAE and weed-free check. Weedy check and those weed management practices, which gave equivalent number of seeds per pod, could not suppress weeds to a greater extent than other treatments (Table 2). Therefore, higher competition for available limited resources ultimately resulted in reduced seed filling of the pods. Similarly, unchecked growth of weeds resulted in the lowest number of seeds pod^{-1} as compared to weed free check in soybean (Peer *et al*., 2013).

Hundred seed weight of common bean

Hundred seed weight was significantly ($P < 0.01$) influenced by sites and weed management practices (Table 3). Hundred seed weight at Hirna was significantly higher by 9.3% than at Haramaya. This could be due to low weed dry weight which caused low weed competition (Table 2).

Weed-free check gave the highest hundred seed weight (22.14 g) that did not vary significantly from s-metolachlor and pendimethalin at 1.0 kg ha^{-1} both supplemented with one hand hoeing and weeding 4 WAE, s-metolachlor at 1.0 kg ha^{-1} + pendimethalin at 1.0 kg ha^{-1} and hand hoeing and weeding 2 WAE. The more and vigorous leaves under weed-free environment might have improved the supply of assimilate to be stored in the grain; hence, the hundred seed weight increased. Furthermore, the highest hundred seed weight recorded from these treatments might be due to availability of more space for better light interception, resulting in better utilization of other growth resources for grain development. Similarly, Peer *et al*. (2013) reported that weed-free treatment gave the highest hundred seed weight in soybean. Following the weed-free treatment, s-metolachlor at 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WAE, significantly increased hundred seed weight by 6.4% over the weedy check plots.

The weedy check plots gave the lowest hundred seed weight (20.55 g). This could be due to high weed competition with crops since this treatment was relatively less effective in suppressing weed growth than other weed management practices (Table 2). Similarly, Peer *et al*. (2013) reported that unchecked weeds, growth in weedy check plots caused the lowest hundred seed weight in soybean.

Table 3. Number of seeds per pod, hundred seed weight and grain yield of common bean as influenced by the main effects of sites and weed management practices

Factors	Number of seeds pod^{-1}	Hundred seed weight (g)	Grain yield (kg ha^{-1})
Sites			
Haramaya	6.8^{a}	20.28^{b}	3501.4^{b}
Hirna	6.4^{b}	22.16^{a}	3878.6^{a}
Significance	**	**	**
LSD (5%)	0.2	0.28	142.5
Weed management practices			
S-metolachlor 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE	7.0^{ab}	21.86^{ab}	4045.3^{ab}
Pendimethalin 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE	6.8^{abc}	21.69^{abc}	3969.8^{abc}
s-metolachlor 1.0 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	6.8^{a-d}	21.46^{a-d}	3859.0^{a-d}
s-metolachlor 0.75 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	6.6^{a-d}	21.33^{b-f}	3704.1^{b-e}
s-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	6.5^{b-e}	21.39^{b-e}	3808.5^{a-d}
s-metolachlor 0.75 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	6.5^{b-e}	21.12^{c-g}	3603.9^{cde}
s-metolachlor 0.5 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	6.5^{b-e}	20.87^{d-g}	3555.9^{de}
s-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	6.6^{b-e}	21.17^{b-g}	3679.7^{b-e}
s-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	6.3^{de}	20.64^{fg}	3342.2^{e}
s-metolachlor 0.5 kg ha^{-1} + Pendimethalin 0.75 kg ha^{-1}	6.4^{cde}	20.69^{efg}	3567.2^{de}
s-metolachlor 0.75 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	6.5^{cde}	20.80^{d-g}	3548.9^{de}
One hand hoeing and weeding 2 WAE	6.7^{a-d}	21.41^{a-e}	3849.9^{a-d}
Weed-free check	7.1^{a}	22.14^{a}	4175.9^{a}
Weedy check	6.1^{e}	20.55^{g}	2949.6^{f}
Significance	*	**	**
LSD (5%)	0.5	0.74	376.9
CV (%)	6.8	3.01	8.8

WAE = weeks after crop emergence; Means followed by the same letters within each column are not significantly different; *, ** significant at P = 0.05 and 0.01, respectively; LSD = least significant difference; CV = coefficient of variation

Grain yield of common bean

The grain yield was significantly ($P < 0.01$) affected by the main effects of sites and weed management practices (Table 3). Grain yield at Hirna was significantly higher by 10.8% than at Haramaya. The higher yield at Hirna over Haramaya could be due to better soil fertility at there (Bethelhem, 2012) as well as more conducive climatic conditions which might have favourably influenced plant growth, development and reproduction. Moreover, yield reduction at Haramaya could be attributed to heavy infestation by weeds; especially broadleaved weeds which grew faster and consequently suppressed the crop growth; thus, causing reduced grain yields. In spite of significant reduction of number of seeds pod^{-1}, the significantly higher number of pods plant^{-1} and hundred seed weight seemed to contribute to increased yield at Hirna (Table 2; Table 2).

The weed-free check plots gave the highest grain yield (4175.9 kg ha^{-1}) that did not vary significantly from s-metolachlor and pendimethalin 1.0 kg ha^{-1} each supplemented with one hand hoeing and weeding 4 WAE, s-metolachlor 1.0 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}, s-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1} and one hand hoeing and weeding 2 WAE. The yield reduction in these treatments, compared to weed-free check, varied between 3.1 and 8.9% which is not substantial. The positive effect of these treatments on number of pods plant^{-1}, seeds pod^{-1} and hundred seed weight might have contributed to higher grain yield (Table 2; Table 3). S-metolachlor 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WAE significantly increased grain yield by 37.1% over the weedy check plots.

Furthermore, weed interference with common bean with pre-emergence application of herbicide combinations could be due to synergistic or additive effect of the herbicides when applied in combinations. The grain yields obtained from plots treated with combination of higher herbicide rates showed yield increase over lower rates. This might be due to lower weed dry weight (Table 2) that might have increased yield attributes (Table 2; Table 3), resulting in an increase in yield. In agreement with this result, weed management with s-metolachlor plus trifluralin plus imazethapyr applied as pre-plant soil incorporated resulted in white bean yields that were equivalent to the weed-free check (Soltani *et al*., 2012). They also reported that weed management with pendimethalin (1.08 kg ha^{-1}) plus imazethapyr applied pre-plant incorporated at 15 to 75 g ha^{-1} resulted in white bean yield that was equivalent to the weed-free check. Similarly, Peer *et al*. (2013) reported that both fluchloralin and pendimethalin (1 kg ha^{-1} each) combined with one hand weeding 35 days after sowing gave far superior yields of soybean than weedy check. Hand weeding had positive contribution on grain yield of common bean by creating suitable soil environment for roots as well as nitrogen fixing bacteria. Therefore, the nitrogen fixing bacteria could improve the soil fertility, which could contribute to the productivity of the plants under this weed management practice.

In general, the significantly higher grain yield of weed-free check, treatment with s-metolachlor and pendimethalin 1.0 kg ha^{-1} each and supplemented with one hand hoeing and weeding 4 WAE, s-metolachlor 1.0 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}, s-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1} and one hand hoeing and weeding 2 WAE, might be the result of easily accessible growth factors (nutrient, moisture and light) for individual plants that produced more flowers and higher net assimilation rate in the absence of competition from weeds than in the weedy check. Besides, the development of more and vigorous leaves under low or no-weed infestation might have improved the photosynthetic efficiency of the crop, resulting in higher grain yield.

Additionally, weed interference with common bean with pre-emergence application of herbicide combinations; s-metolachlor 1.0 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}, and s-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1} reduced yield of common bean by 7.6 and 20.0%, respectively, compared to the weed-free check (Table 3). The reason could be that at higher rates of herbicides combinations yield losses could be low since weed management would be better in higher herbicides rates. Similarly, Soltani and Sikkema (2005) reported that flumetsulam plus s-metolachlor pre-mixed at 1443 g ha^{-1} resulted in decreased yield by 14% in white bean. The grain yield in higher herbicides application rates had shown an increase over their respective lower rates in combination. This might be due to lower weed management efficiency (Table 2) under lower rates, resulting in lower yield attributes and yield (Table 2; Table 3).

Economic Feasibility of weed management practices in common bean

Sites and weed management practices significantly ($P < 0.01$) influenced grain yield. Therefore, an economic analysis was performed on the combined yield data using the partial budget technique (CIMMYT, 1988). The result of the partial budget analysis and the data used for the partial budget analysis is given are Table 4.

The economic analysis revealed that the highest net benefit of Birr 33601 ha^{-1} was obtained from application of s-metolachlor 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE which was 32.5% higher than the net benefit from weedy check (Table 4). The reason could be in the case of s-metolachlor 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE, weeds were suppressed by herbicide at early stage and the later emerged weeds were controlled by one hand hoeing and weeding then after weeds were suppressed by the crop canopy. Therefore, the weed dry weight was reduced (Table 2) as the result yield was increased (Table 3). Moreover, the highest net benefit from this treatment could be attributed to high yield and low cost of herbicides compared to the labour cost. In conformity 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 (ETB 12296 ha^{-1}) in common bean.

On the other hand, the lowest net benefit from weedy check was attributed to low yield due to weed competition. From the economic point of view, it was obvious that s-metolachlor 1.0 kg ha^{-1} + one hand hoeing was more profitable than the rest of weed management practices.

CONCLUSION

Among the weed management practices evaluated, s-metolachlor 1.0 kg ha^{-1} supplemented with one hand weeding four weeks after crop emergence reduced the weed dry weight, increased the yield and yield components of common bean as well as economic benefit. The economic benefit gained from s-metolachlor 1.0 kg ha^{-1} supplemented with one hand weeding four weeks after crop emergence was 32.5% greater than from the value obtained from the weedy check.

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Table 4. Partial budget analysis to estimate net benefit for weed management practices of common bean averaged for sites

Weed management practices	**Average yield (kg ha^{-1})**	**Adjusted yield (kg ha^{-1})**	**Gross benefit (ETB ha^{-1})**	**Total cost that varied (ETB ha^{-1})**	**Net benefit (ETB ha^{-1})**
S-metolachlor 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE	4045	3641	34769	1168	33601
Pendimethalin 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WAE	3970	3573	34120	1702	32418
S-metolachlor 1.0 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	3859	3473	33168	1120	32048
S-metolachlor 0.75 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	3704	3334	31837	1066	30771
S-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	3809	3428	32734	932	31802
S-metolachlor 0.75 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	3604	3244	30976	878	30098
S-metolachlor 0.5 kg ha^{-1} + pendimethalin 1.0 kg ha^{-1}	3556	3200	30563	1011	29552
S-metolachlor 1.0 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	3680	3312	31627	744	30883
S-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	3342	3008	28726	635	28091
S-metolachlor 0.5 kg ha^{-1} + pendimethalin 0.75 kg ha^{-1}	3567	3210	30660	823	29837
S-metolachlor 0.75 kg ha^{-1} + pendimethalin 0.5 kg ha^{-1}	3549	3194	30503	690	29813
One hand hoeing and weeding 2 WAE	3850	3465	33090	800	32290
Weedy check	2950	2655	25352	0	25352

ETB = Ethiopian Birr; WAE = weeks after crop emergence; Cost of Pendimethalin and S-metolachlor 752 and ETB 218 per kg, respectively; Spraying ETB 150 ha^{-1}; Cost of lobour ETB 50 per person day; Sale price of common bean ETB 11 kg^{-1}; Field price of common bean ETB 9.55 kg^{-1}; Cost of harvesting, threshing and winnowing ETB 135 per 100 kg; packing and material cost ETB 4.50 per 100 kg and transportation ETB 6.50 per 100 kg; ETB = 0.0481 USD (August 12, 2015).

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