Effect of Plant Spacing and Weeding Frequency on Weed Infestation, Yield Components, and Yield of Common Bean (*Phaseolus vulgaris* L.) in Eastern Ethiopia

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Abstract: Common bean is an important food and cash crop in eastern Ethiopia. However, its yield is constrained by weeds. Therefore, this study was conducted in 2012 main cropping season at Haramaya and Hirna research fields, eastern Ethiopia, to determine the effect of plant spacing and weeding frequency on weeds, yield components and yield of common bean. The experiment comprised 18 treatment combinations with three inter- and intra-row plant spacing, respectively, (30 cm × 10 cm, 30 cm × 15 cm, 40 cm × 10 cm) and six weeding frequencies (one weeding by hand-hoeing two weeks after crop emergence, one weeding by hand-hoeing three weeks after crop emergence, one weeding by hand-hoeing four weeks after crop emergence, two weeding by hand-hoeing two and five weeks after crop emergence, weed-free check, weedy check). The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times per treatment. It was observed that broad-leaved weed species were dominant at both sites with relative density of 61.2 and 73.2% at Haramaya and Hirna, respectively. Interaction of sites, plant spacing and weeding frequencies significantly affected weed density and dry weight. Days to flowering, days to physiological maturity, plant height, number of pods per plant, number of seeds per pod, hundred seed weight, grain yield, aboveground dry biomass, and harvest index significantly affected by weeding frequencies. Combination of plant spacing of 30 cm x 10 cm and two weeding by hand-hoeing two and five weeks after crop emergence significantly reduced the weed dry weight by 95.3 and 95.8% at Haramaya and Hirna, respectively, as compared to the same plant spacing with no weeding throughout the season. Common bean plants weeded by hand-hoeing twice two and five weeks after crop emergence flowered significantly earlier next to plants kept weed-free. Significantly higher number of pods per plant, grain yield (2984.0 kg ha^{-1}) and aboveground dry biomass were obtained at Hirna than at Haramaya. However, significantly, higher numbers of seeds per pod and harvest index were obtained at Haramaya than at Hirna. Significantly higher grain yield (2612.2 kg ha^{-1}) and (2718.8 kg ha^{-1}) were obtained from one weeding by hand-hoeing two weeks after crop emergence and two weeding by hand-hoeing two and five weeks after crop emergence next to weed-free check, respectively. However, the economic analysis revealed that the highest net benefit of 15924 ETB ha^{-1} was obtained in response to combining the spacing of 30 cm × 10 cm with twice weeding by hand-hoeing two and five weeks after crop emergence. It could be concluded that planting common bean plants at the spacing of 30 cm between rows and 10 cm between plants and weeding the crop by hand-hoeing twice at two and five weeks after crop emergence resulted in optimum growth and grain yield of the crop.

Keywords: Grain Yield; Hand-hoeing; Harvest Index; Net Benefit; Weed; Weed Dry Weight

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the major food and cash crops in Ethiopia and it has substantial national economic significance. However, its producti-ion is limited by several constraints of which weeds are a major culprit. Uncontrolled weed populations can substantially reduce the yield of common bean up to 90% (Tilahun, 1998; Rezene and Kedir, 2008; Mengesha *et al.*, 2013).

Growth and development of weeds can be suppressed by plant spacing, planting pattern of crop plants and weeding frequencies. Closely spaced crop provides good smothering potential on growth and development of weeds due to less availability of space for growth and development, and also well distribution of seedlings per unit area, thereby competing for nutrients and moisture better than the weeds do. A crop's ability to suppress weeds can be enhanced if it is able to pre-empt limiting resources by acquiring them earlier in the growing season or sequestering them in the form of more crop plants per unit area (Page and Willenborg, 2013).

Various studies indicated that plant spacing and planting pattern significantly influence the incidence of an infestation by weeds and the performance of crop plants due to their competition for limited natural resources. Ghadiri and Bayat (2004) reported that the ability of plants to reduce weed dry weight was further enhanced in medium (60 cm) and narrow (45 cm) inter row spicing compared to wide rows (75 cm) in Pinto bean (*P. Vulgaris* L.). Furthermore**,** yield and economic benefits are sufficient to support the production of soybean [*Glycine max* (L.) Merr.] in narrow (38 cm) rows

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(Bruin and Pedersen, 2008). A similar study in common bean (*P. Vulgaris* L.) showed that yield increase and weed suppression were maximized in narrow rows (38 cm) than wider rows (76 cm) (Holmes and Sprague, 2013). Moreover, Blackshaw *et al.* (2000) reported that in the presence of weeds, narrow rows and high plant densities increased yield of dry bean (*P. Vulgaris* L.).

Hand weeding is the major weed control method in pulse production in Ethiopia (Rezene and Kedir, 2008). The results of various studies showed that the frequencies of hand weeding had impacts on weed infestation and crop yield on common bean in Ethiopia. Tenaw *et al.* (1997) reported that hand weeding affected weed infestation intensity and crop yield parameters of common bean. One time early weeding at 25 days after crop emergence resulted in 70% yield increase of common bean compared to no weeding (Rezene and Kedir, 2008). Similarly, Tilahun (1998) reported that at least two early weeding (i.e. consecutive weeding at 15 and 30 days after crop emergence) results in efficient weed control, which leads to significantly higher yields of common bean.

However, no information is available in eastern Ethiopia on how plant spacing and weeding frequencies affect weed management in common bean or fit into an integrated weed management strategy. Moreover, the effects of weed management practices vary with crop varieties, weed species, soil types, climatic conditions, previous cropping practices and the interest of the producer.

Therefore, this study was conducted to evaluate the effect of plant spacing and weeding frequencies on weed infestation, yield components, and yield of common bean.

2. Materials and Methods

2.1. Description of the Study Sites

The experiment was conducted at Haramaya (09° 26´ N latitude and 42° 03´ E longitude, and altitude of 2006 meters above sea level) in 2012 main cropping season and Hirna (09° 15´ N latitude and 41° 06´ E longitude, and altitude of 1870 meters above sea level), in eastern Ethiopia, in the same year and season. The soil of the experimental site at Haramaya has organic matter content of 1.0% (low), total nitrogen content of 0.17% (moderate), available phosphorus content of 8.72 mg kg soil^{-1} (low), pH of 8.13 (strongly alkaline) and with sandy loam texture (Cottenie, 1980; Tekalign, 1991; Bethelhem, 2012). The soil of Hirna had organic matter content of 1.4% (low), total nitrogen content of 0.22% (moderate), available phosphorus content of 32 mg kg soil^{-1} (very high), pH of 6.79 (neutral) and with clay texture (Cottenie, 1980; Tekalign, 1991; Bethelhem, 2012).

Total rainfall during the cropping season (July-October) was 474 and 548 mm at Haramaya and Hirna, respectively. The mean minimum and maximum temperatures during the main cropping season were 12 and 24°C at Haramaya, respectively, with the corresponding records of 13 and 27°C for Hirna (Figure 1).

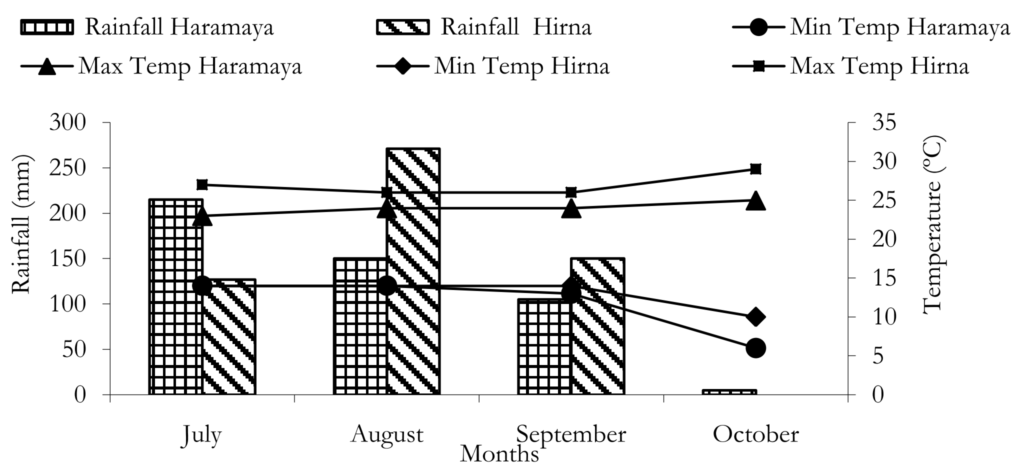

Figure 1. Rainfall (mm), minimum and maximum temperatures (ºC) recorded at Haramaya and Hirna during 2012 main cropping season (Source: Jigijiga Meteorological Station).

2.2. Treatments and Experimental Design

The experiment comprised 18 treatment combinations with three inter- and intra-row plant spacing, respectively, (30 cm × 10 cm, 30 cm × 15 cm, 40 cm × 10 cm) and six weeding frequencies [W_1 = one weeding by hand-hoeing two weeks after crop emergence (WAE), W_2= one weeding by hand-hoeing three WAE, W_3 = one weeding by hand-hoeing four WAE, W_4 = two weeding by hand-hoeing two and five WAE, W_5 = weed-free check, and W_6 = weedy check]. The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times per treatment.

2.3. Experimental Procedures

The experimental field was prepared to seedbeds of a fine tilth using a tractor. The gross plot size was 3.6 m × 2.4 m (8.64 m^2), with 12 and 9 rows in 30 and 40 cm inter row spacing, while there were 24 and 16 plants in each row with intra-row spacing of 10 and 15 cm, respectively. The outermost one row from one side and two rows from other side for 40 cm inter-row and two rows from both sides for 30 cm inter-row spacing were considered border rows. Three plants for 10 cm intra-row and two plants for 15 cm intra-row spacing from each end of the rows were considered as the border plants. Thus, the net plot had 8 and 6 rows under 30 cm and 40 cm row spacing, respectively, and the net plot size was 2.4 m × 1.8 m (4.32 m^2).

Seed of the export type common bean variety Awash Melka, which was released by Melkassa Agricultural Research Centre in 1998, was planted at Hirna and Haramaya on 13^{th} and 18^{th} July 2012, respectively. Diammonium phosphate (DAP) (18% N and 46% P_2O_5 ha^{-1}) was drilled in furrows at the rate of 100 kg ha^{-1} at planting as per recommendation (Mandefro *et al*., 2009). Weeds were removed by weeding by hand-hoeing as required in the case of the weed-free treatment. Harvesting was done manually at Hirna and Haramaya on 28 October and 6 November 2012, respectively. The biomass after harvest was sun-dried for 10 days and threshing and winnowing were done subsequently.

2.4. Data Collection

The weed flora present in the experimental fields were recorded from the weedy check plots by placing a quadrat (0.25 m × 0.25 m) randomly at two spots in each replication just before flowering of the crop, which was converted into m^{-2}. The species were categorized into their botanical families with aid of flora books (Stroud and Parker, 1989; Melaku, 2008) and expertise. Moreover, weeds were collected by using a quadrat of 0.25 m × 0.25 m thrown randomly at two places from each plot 15 days before crop harvest to determine the weed density. The weeds at this stage were also cut near the ground and, after three days of sun-drying, the samples were oven-dried at 65^{o}C to a constant weight to determine dry weight. The weed density and dry weight were subjected to square root transformation $\sqrt{x+0.5}$ where x is the original value to ensure normality of the data before analysis.

Number of days to flowering was recorded as the number of days from sowing to the time when 50% of the 10 pre-tagged plants showed first flower. Similarly, 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 plants senesced and the leaves and pods turned yellow in colour. The total number of pods in 10 randomly taken plants in each plot was counted at harvest and expressed as the average number of pods per plant. From these pods, seeds were counted to determine the average number of seeds per pod. Hundred seeds were counted from each plot, and their weights were recorded. The aboveground dry biomass weight was measured at physiological maturity by cutting at ground level, 10 randomly sampled plants and sun drying the biomass. This sun-dried aboveground biomass was multiplied by the number of plants in the net plot area and then converted into kg ha^{-1}. Grain yield (kg) was recorded from each net plot area. The moisture content of the grain was determined for each plot and adjusted to 10.5%. Harvest index was calculated as the ratio of grain yield to the total aboveground dry biomass yield.

2.5. Statistical Data Analysis

The data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure of 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) and since the F-test had shown homogeneity of the variances of the two sites, combined analysis was used for the two sites. Least significant difference (LSD) test at 5% probability level was employed to separate treatment means where significant treatment differences existed.

2.6. 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 output at the time the crop was harvested. 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 expect 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 cost that varied included the sum of cost of seed and labour cost where hand weeding is 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.

3. Results and Discussion

3.1. Weed Flora in the Experimental Fields

The experimental fields were infested with weeds, including broad-leaved, sedge and grass weeds (Table 1). Broad-leaved weed species were dominant at both sites with relative densities of 61.2 and 73.2% at Haramaya and Hirna, respectively. Weed species diversity was higher at Haramaya (10) than at Hirna (7). The possible reason for more species occurrence at Haramaya could be the difference in soil type, altitude, previous crop grown in the sites and more rainfall at Haramaya relative to Hirna at early stage of the crop growth (Figure 1). 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 influenced weed species distribution in eastern Ethiopia.

Table 1. Density (m^{-2}) and relative density (%) of weed species in the experimental fields of common bean during 2012 main cropping season.

Weed Species	Family	Haramaya Weeds density(m^{-2})	Haramaya Relative density (%)	Hirna Weeds density(m^{-2})	Hirna Relative density (%)
Broadleaved					
Amaranthus dubius TheIl.	Amaranthaceae	2	1.1	30	17.9
Commelina benghalensis L.	Commelinaceae	8	4.3	11	6.5
Convolvulus arvensis L.	Convolvulaceae	2	1.1	-	
Datura stramonium L.	Solanaceae	-		15	8.9
Equisetum arvense L.	Equisetaceae	12	6.5	-	-
Erucastrum arabicum Fisch. and Mey.	Brassicaceae	15	8.1	12	7.1
Galinsoga parviflora Cav.	Asteraceae	53	29.1	5	3.0
Parthenium hysterophorus L.	Asteraceae			50	29.8
Plantago lanceolata L.	Plantaginaceae	20	11.0	-	
Total			61.2		73.2
Sedge					
Cyperus rotundus L.	Cyperaceae	52	28.5	45	26.8
Grass					
Digitaria ternata (A.Rich) Stapf.	Poaceae	17	9.2	-	-
Setaria verticillata L. P.Bauv.	Poaceae	1	1.1	-	-
Total			10.3		26.8

3.2. Weed Density and Dry Weight at Harvest

3.2.1. Weed density

Interaction of plant spacing, weeding frequencies and sites had significant ($p \leq 0.01$) effect on total weed density (Table 2). The highest (14.2 m^{-2}) total weed density was obtained from 30 cm × 15 cm plant spacing and the weedy check from Haramaya that was significantly higher than the rest of the treatments at both sites (Table 3). The reason for higher weed density could be the wider intra-row spacing that might have provided adequate and more space for weeds to occupy than the other plant spacing.

On the other hand, the significantly higher weed density at Haramaya than at Hirna could be due to more rainfall at early crop growth stage that may have favoured the establishment and survival of weeds (Figure 1). Furthermore, the sandy loam soil texture at Haramaya might be more suitable for the germination and emergence of weed seeds than clay texture at Hirna. In agreement with this result, Gulshan and Dasti (2012) reported that sandy loam soil texture was better for maximum germination and emergence of weed seeds than clay loam texture.

At harvest, no weed species were found in 30 cm × 10 cm plant spacing combined with two weeding by hand-hoeing two and five WAE. Furthermore, interaction of 30 cm × 10 cm plant spacing combined with two weeding by hand-hoeing two and five WAE reduced the weed density by 92.6 and 88.5% at Haramaya and Hirna, respectively, as compared to the same plant spacing not weeded throughout the season (Table 3). This could be attributed to competitive advantage to crop; the later emerging weeds were suppressed by taller crop plants more under closer spacing, thereby resulting in reduced total weed density. Moreover, two weeding by hand-hoeing two and five WAE might have helped in reducing the weed density by decreasing weed seed bank due to early weeding and later emerged weeds might have been knocked down physically by subsequent weeding. In line with this result, weed suppression was maximized in narrower (38 cm) than wider (76 cm) row spacing in common bean (Holmes and Sprague, 2013). Similarly, low soil disturbance systems are likely to leave a large portion of the weed seed bank on or near the soil surface after crop sowing, resulting in higher seedling emergence than high soil disturbance systems (Feldman *et al*., 1997). In agreement with the current finding, Tilahun (1998) reported that common bean required at least two early weeding (15 and 30 days after emergence) for efficient weed management, which led to significantly higher crop yields.

Table 2. Mean squares of analysis of variance for weed and common bean parameters due to site, spacing, weeding frequency and their interaction at Haramaya and Hirna during 2012 cropping season.

	Source of variation					
Parameters	Site (1)	Spacing (2)	Weeding Frequency (5)	Spacing × weeding Frequency (10)	Site × Spacing × weeding Frequency (17)	Error (68)
Total weeds density	295.115**	24.708**	200.882**	4.045**	7.742**	0.189
Weed dry weight	4.457*	121.785**	1067.743**	22.968**	14.557**	1.097
Days to flowering	1459.343**	1.676NS	26.854**	0.565NS	1.264NS	1.281
Days to maturity	330.750**	1.861NS	33.928**	1.872NS	1.534NS	5.103
Plant height	33259.005**	2.383NS	596.005**	23.535NS	63.318NS	112.895
Number of pods per plant	3294.558**	7.630 NS	199.561**	8.975 NS	7.895NS	1426.204
Number of seeds per pod	25.569**	0.223NS	1.547**	0.052NS	0.194NS	18.464
Hundred seed weight	0.230NS	1.852NS	5.051*	1.538NS	1.174NS	1.882
Grain yield	28022018.31**	218643.30NS	2354160.96**	31812.09NS	132060.75NS	112691.03
Aboveground biomass	870387561.8**	500114.3NS	14165961.1**	1054705.4NS	696128.1NS	2277832
Harvest Index	1327.217 **	20.725NS	71.315NS	39.499NS	49.591NS	35.270

*NS, * and ** are non-significant, significantly different at 5% P level and significantly different at 1% P level, respectively; Figures in parentheses are the degree of freedom.*

3.2.1. Weed dry weight

Interaction of plant spacing, weeding frequencies and sites significantly ($p \leq 0.01$) affected weed dry weight (Table 2). The highest (28.5 g m^{-2}) weed dry weight, which was significantly different from the rest of the treatments, was obtained from 30 cm × 15 cm plant spacing from the weedy check at Hirna (Table 3). Further, this interaction had significantly higher weed dry matter weight than the other plant spacing under weedy check. This means that the availability of more space for the weeds under wide spacing resulted in significantly higher density than the other spacing that might have resulted in higher weed dry weight.

Similarly, reduced weed dry weight over weedy check was obtained by Singh and Rao (1992) and Tilahun (1998). Meseret *et al.* (2008) also reported higher weed dry weight from weedy check in common bean. Körner (2006) found that the warm climate adapted weed species would take additional advantages from higher temperatures that result in relatively greater acceleration of the rate of growth. Singh and Sekhon (2013) also reported higher weed dry matter due to high rainfall. In agreement with these findings, in this experiment also high rainfall and temperature might have also resulted in more growth, development and accumulation of dry matter in weeds at Hirna than at Haramaya (Figure 1).

In general, narrower plant spacing (30 cm × 10 cm) reduced weed dry weight significantly compared to the wider plant spacing with 40 cm × 10 cm and 30 cm × 15 cm suggesting that closely spaced crop provided good smothering potential on growth and development of weeds due to less availability of space as well as shading. Interaction of 30 cm × 10 cm plant spacing combined with two hand weeding and hoeing at two and five WAE reduced the weed dry weight by 95.3 and 95.8% at Haramaya and Hirna, respectively, as compared to the same plant spacing not weeded throughout the season. Similarly, Ghadiri and Bayat (2004) reported that the ability of plants to reduce weed dry weight was further enhanced in medium (60 cm) and narrow rows (45 cm) compared to wide rows (75 cm) in Pinto bean.

Table 3. Interaction effects of plant spacing, weeding frequency and site on weed density and dry weight at crop harvest during 2012 main cropping season.

Plant spacing	Weeding frequency (W)	Weed density (m^{-2})		Weed dry weight ($g\ m^{-2}$)	
		Haramaya	Hirna	Haramaya	Hirna
30 cm × 10 cm	W1	8.0^{ef} (64.3)	2.4^{kl} (5.3)	7.4^{ij} (54.2)	10.6^{g} (111.3)
	W2	6.3^{gh} (39.7)	0.7^{n} (0.0)	5.8^{j-m} (32.7)	0.7^{q} (0.0)
	W3	4.6^{i} (21.3)	0.7^{n} (0.0)	4.1^{mno} (16.0)	0.7^{q} (0.0)
	W4	0.7^{n} (0.0)	0.7^{n} (0.0)	0.7^{q} (0.0)	0.7^{q} (0.0)
	W5	0.7^{n} (0.0)	0.7^{n} (0.0)	0.7^{q} (0.0)	0.7^{q} (0.0)
	W6	9.4^{c} (88.0)	6.1^{gh} (38.0)	14.8^{de} (220.3)	16.5^{d} (273.7)
30 cm × 15 cm	W1	9.2^{c} (84.0)	4.2^{ij} (17.0)	13.3^{ef} (183.7)	13.9^{ef} (193.7)
	W2	7.5^{f} (55.3)	2.3^{kl} (5.0)	7.1^{ijk} (49.3)	9.3^{gh} (86.0)
	W3	6.2^{gh} (37.3)	0.7^{n} (0.0)	5.5^{klm} (30.3)	0.7^{q} (0.0)
	W4	3.8^{j} (15.0)	0.7^{n} (0.0)	3.2^{nop} (10.0)	0.7^{q} (0.0)
	W5	0.7^{n} (0.0)	0.7^{n} (0.0)	0.7^{q} (0.0)	0.7^{q} (0.0)
	W6	14.2^{a} (202.3)	10.6^{b} (112.0)	23.4^{b} (549.2)	28.5^{a} (812.0)
40 cm × 10 cm	W1	8.8^{cd} (76.7)	2.5^{k} (6.0)	7.6^{hi} (57.3)	12.9^{f} (168.3)
	W2	6.7^{g} (45.0)	1.8^{lm} (3.3)	6.3^{i-l} (39.0)	2.9^{op} (10.7)
	W3	5.6^{h} (31.3)	0.7^{n} (0.0)	4.7^{lmn} (21.7)	0.7^{q} (0.0)
	W4	1.6^{m} (2.7)	0.7^{n} (0.0)	2.0^{pq} (4.3)	0.7^{q} (0.0)
	W5	0.7^{n} (0.0)	0.7^{n} (0.0)	0.7^{q} (0.0)	0.7^{q} (0.0)
	W6	10.2^{b} (103.0)	8.4^{de} (70.0)	21.1^{c} (445.0)	20.0^{c} (407.0)
$LSD_{(0.05)}$		0.7		1.7	
CV (%)		10.4		15.0	

Figures in parentheses are the original values; Means followed by the same letter within each column and row for the parameters are not significantly different; LSD = least significant difference; CV = coefficient of variations; W = Weeding frequency; W1, W2, W3, are weeding by hand-hoeing at 2, 3 and 4 WAE, respectively; W4, W5 and W6 two weeding by hand-hoeing at 2 and 5 WAE, weed-free and weedy check, respectively.

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3.3. Crop Phenology and Plant Height of Common Bean

3.3.1. Days to flowering and physiological maturity

Days to flowering and physiological maturity of common bean were significantly ($p \leq 0.01$) affected by main effects of sites and weeding frequencies, while plant spacing had no significant effect (Table 2). Days to 50% flowering and 90% physiological maturity were attained faster by eight and three days, respectively, at Hirna compared to Haramaya (Table 4). The possible reason for earlier flowering and physiological maturity at Hirna could be attributed to lower weed density or infestation and relatively higher temperature and rainfall, which may have shortened crop phenology (Table 3; Figure 1). On the other hand, plant spacing had no significant effect on days to 50% flowering and 90% physiological maturity. This current result is in line with the observation of Blackshaw *et al.* (2000) who stated that maturity of dry bean was not affected by row spacing.

The days to flowering and maturity in weed-free plots were significantly earlier than the other treatments, while no significant difference existed between weed-free check and two weeding by hand-hoeing two and five WAE. This indicates that the number of days to flowering and physiological maturity was significantly delayed due to weed infestation throughout the crop growth over other treatments.

The shading out of crop plants by the weeds might have reduced sunlight penetration, thereby prolonging the vegetative growth and resulting in delayed flowering and physiological maturity of common bean. This might have reduced the vegetative growth and delayed the transition to the reproductive period and, finally, to physiological maturity. In line with this result, Mitiku *et al.* (2012) reported that with increase in the dry weight of *Parthenium*, the duration required by the common bean plants to reach physiological maturity was prolonged.

Table 4. Crop phenology and plant height of common Bean as influenced by the main effects of sites, plant spacing and weeding frequencies during 2012 main cropping season.

Factors	Days to 50% flowering	Days to 90% physiological maturity	Plant height (cm)
Sites			
Haramaya	59[a]	100[a]	68.9[b]
Hirna	51[b]	97[b]	104.0[a]
LSD $_{(0.05)}$	0.4	0.9	4.1
Plant spacing			
30 cm × 10 cm	55	98	86.5
30 cm × 15 cm	55	99	86.2
40 cm × 10 cm	55	99	86.7
LSD $_{(0.05)}$	NS	NS	NS
Weeding frequencies			
One weeding by hand-hoeing 2 WAE	55[c]	99[b]	83.6[bcd]
One weeding by hand-hoeing 3 WAE	55[c]	99[b]	86.7[bc]
One weeding by hand-hoeing 4 WAE	56[b]	99[b]	90.4[ab]
Two weeding by hand-hoeing 2 and 5 WAE	54[d]	98[c]	83.1[cd]
Weed-free check	53[e]	97[c]	79.5[d]
Weedy check	57[a]	101[a]	95.5[a]
LSD $_{(0.05)}$	0.8	1.5	7.1
CV (%)	2.1	2.3	12.3

WAE = weeks after crop emergence; CV = coefficient of variations; LSD = least significant difference; Means followed by the same letters within each column are not significantly different.

3.3.2. Plant height

Plant height was significantly ($p \leq 0.01$) affected by main effects of sites and weeding frequencies but not by plant spacing (Table 2). Common bean plants at Hirna were significantly taller than plants at Haramaya (Table 3), possibly due to more rainfall and relatively higher temperature at Hirna (Figure 1), which could enhance the growth and development of the plants. Furthermore, the soil fertility condition at Hirna, especially organic matter, total nitrogen, and available phosphorus was better at Haramaya (Bethelhem, 2012).

There was no significant effect of plant spacing on plant height. This is in agreement with the report of Blackshaw *et al.* (2000) who did not observe any effect of row spacing or plant density on plant height of common bean. In line with this, Chauhan and Opeña, (2013) stated that plant height of soybean was not influenced by the plant geometry. In contrast to these result, however, increased plant density increased plant height of field peas (Sharma, 2002), soybean (Bruin and Pedersen, 2008), faba bean (Khalil *et al*., 2010) and field pea (Yayeh *et al.,* 2014).

Plants, which were kept weed-free throughout the season, were significantly shorter (79.5 cm) than the plants in plots in weedy check and once weeded at three or four WAE (Table 3). This might be due to no or little competition posed by the weeds resulting in non-spindly, stouter and thicker or sturdy plants. On the other hand, plants, which were not weeded throughout the season, were spindly and tall (95.5 cm) than plants subjected to the other weeding treatments except plants which were weeded once by hand-hoeing at four WAE (Table 4). This might be due to the exposure of plants in weedy check to competition by the weeds throughout the season while plants in early competition caused by the weeding delayed to four WAE might have encountered competition for various growth factors especially for sunlight. The height increment in weedy check could be attributed to the increased weed density and the crop might have been subjected to high competition for sunlight as well as for space, moisture and nutrients.

3.4. Yield Components of Common Bean

3.4.1. Number of pods per plant

Number of pods per plant was significantly ($p \leq 0.01$) affected by main effects of sites and weeding frequency, while plant spacing had no significant effect on number of pods per plant (Table 2). Significantly higher number (60%) of pods per plant were obtained at Hirna than at Haramaya (Table 5). Significantly higher plant height at Hirna might have helped in the production of more flower bearing sites. On top of this, at Hirna favourable rainfall, temperature and soil conditions seemed to facilitate higher net assimilation rate; hence, retaining more flowers.

Higher number of pods plant^{-1} in weed-free check might be due to the absence of competition from weeds as the plots were kept weed-free throughout the cropping season. In addition, the development of more and vigorous leaves might have helped the crop to improve the photosynthetic efficiency that may have nourished large number of pods (Hodgson and Blackman, 2005). Early weeding at two WAE also enhanced number of pods plant^{-1}, which could be attributed to better competition of the crop for growth resources against weeds. Likewise, Ayaz *et al.* (2001) stated that the number of pods produced per plant or maintained up to the final harvest depends on a number of environmental and management practices. Similar results were reported on chickpea (Rashid *et al.*, 2009; Fathi *et al.*, 2010; Tepe *et al.*, 2011) and mung bean (Khan *et al.,* 2008) where weed interference decreased the number of pods per plant.

Table 5. Number of pods per plant, seeds per pod and hundred seed weight of common bean as influenced by the main effects of sites, plant spacing and weeding frequency during 2012 main cropping season.

Factors	Number of pods plant^{-1}	Number of seeds pod^{-1}	Hundred seed weight (g)
Sites			
Haramaya	18.5^{b}	6.6^{a}	14.8
Hirna	29.6^{a}	5.6^{b}	14.7
LSD $_{(0.05)}$	1.8	0.2	NS
Plant spacing			
30 cm × 10 cm	23.7	6.2	14.6
30 cm × 15 cm	24.6	6.1	15.0
40 cm × 10 cm	23.9	6.0	14.6
LSD $_{(0.05)}$	NS	NS	NS
Weeding frequencies			
One weeding by hand-hoeing 2 WAE	25.0^{ab}	6.2^{ab}	14.6^{b}
One weeding by hand-hoeing 3 WAE	23.6^{b}	6.0^{b}	14.4^{b}
One weeding by hand-hoeing 4 WAE	22.1^{b}	6.0^{bc}	14.6^{b}
Two weeding by hand-hoeing 2 and 5 WAE	26.9^{a}	6.3^{ab}	14.8^{ab}
Weed-free check	28.0^{a}	6.5^{a}	15.7^{a}
Weedy check	18.9^{c}	5.6^{c}	14.2^{b}
LSD $_{(0.05)}$	3.0	0.3	0.9
CV (%)	19.0	8.6	9.3

WAE = weeks after crop emergence; CV = coefficient of variations; LSD = least significant difference; Means followed by the same letters within each column are not significantly different.

Plants which were not weeded throughout the season had the lowest (18.9) number of pods per plant. This might be due to season-long competition from weeds, which might have reduced the number of pods per plant. In line with this result, it was reported that season-long weed competition significantly reduced the number of pods per plant for white bean (Malik *et al.*, 1993) and for Pinto beans (Ghadiri and Bayat, 2004).

3.4.2. Number of seeds per pod

Number of seeds per pod was significantly ($p \leq 0.01$) affected by the main effects of sites and weeding frequencies but not by plant spacing (Table 2). There was significantly higher (6.6) number of seeds per pod at Haramaya (Table 5), which could be due to lower number of pods per plant at Haramaya. Since there was lower number of pods per plant, competition among pods could be reduced, which might have resulted in more number of seeds per pod. The absence of significant difference in number of pods due to plant spacing is in agreement with the finding of Shahidullah and Hossain (1987) and Ihsanullah *et al.* (2002) who reported no significant effect of row spacing on number of seeds pod^{-1} in mung bean. In contrast, however, Turk and Tawaha (2002) reported that plant density was negatively correlated with number of seeds pod^{-1} in faba bean.

Plants which were kept weed-free throughout the season had the highest (6.5) number of seeds per pod, which is statistically at par with the number of seeds per pod from plants that were once hand weeded at two WAE as well as twice at two and five WAE. This difference in the number of grains might, therefore, be due to reduction of weed competition which resulted in more translocation and assimilation of photosynthates towards grain formation (Borras *et al.,* 2004). In line with this, Tenaw *et al.* (1997) and Sharma *et al.* (2004) also reported that number of seeds pod^{-1} of common bean significantly decreased with the increased weed infestation and significantly increased with the weed-free period.

The plants which were not weeded throughout the season had the lowest (5.6) number of seeds per pod, which was statistically at par with the number of seeds per pod obtained from plants in plots that received hand-hoeing at four WAE. This might be due to competition posed by the weeds when allowed to grow throughout the crop growth, while late weeding might have also created conducive condition to weeds to compete with crops, resulting in reduced number of seeds per pod. Similarly, season-long weed competition significantly reduced total number of seeds per pod of common bean (Malik *et al*., 1993; Abiy and Fasil, 2009).

3.4.3. Hundred seed weight

Hundred seed weight was significantly ($p \leq 0.05$) affected by weeding frequencies, while sites and plant spacing had no significant influence on this parameter (Table 2). Plants, which were kept weed-free throughout the season, had the highest (15.7 g) hundred seed weight, which was statistically at par with hundred seed weight obtained from plants that were hand-hoed twice at two and five WAE (Table 4). This might be due to reduced competition for growth resources, which might have enabled the plants access to availability of nutrients and better translocation of photosynthates from source-to-sink, resulting in higher accumulation of photosynthates in the seeds.

Plants, which were not weeded throughout the season, had the lowest (14.2 g) hundred seed weight. This value was statistically at par with the hundred seed weight obtained from the rest of the weeding frequencies with the exception of weed-free check. Similarly, it was reported that season-long weed competition significantly reduced hundred seed weight of white bean (Malik *et al*., 1993) and Pinto bean (Ghadiri and Bayat, 2004).

3.4.4. Grain yield

Grain yield was significantly ($p \leq 0.01$) affected by main effects of sites and weeding frequencies but not by plant spacing (Table 2). Significantly higher (2984.0 kg ha^{-1}) grain yield was obtained at Hirna than at Haramaya (Table 6). The grain yield obtained at Hirna exceeded that obtained at Haramaya by about 52% (Table 6). This might be due to better growing conditions for the crop at Hirna than at Haramaya. Despite no significant difference in hundred seed weight and significantly lower number of seeds pod^{-1} at Hirna, the significantly higher number of pods plant^{-1} might have contributed to significant increase in yield at Hirna than at Haramaya (Table 5; Table 6).

The establishment of crop with uniform and dense plant distribution may result in better use of sunlight, water and nutrients and may lead to more competitive ability (Minotti and Sweet, 1981). However, there was no significant difference in yield due to plant spacing. Contrary to this current finding, a reduction in inter-row spacing from 69 to 23 cm increased yield by 19% and an increase in density from 20 to 50 plants m^{-2} increased yield by 17%in dry bean (Blackshaw *et al*., 2000). However, some researchers (Burnside, 1979; Murdock *et al*., 1986; Howe and Oliver, 1987) observed no effect of row spacing on white bean or soybean yield, while others observed a positive yield response under narrow row spacing (Williams *et al*., 1973; Goulden, 1976; Redden *et al*., 1987; Grafton *et al*., 1988; Malik *et al*., 1993).

Plants which were kept weed-free throughout the season had the maximum (2829.0 kg ha^{-1}) grain yield, which was statistically at par with grain yield obtained from plants that were hand-hoed once at two WAE and twice at two and five WAE. This might be due to reduced competition from weeds. Similarly, Rezene and Kedir (2008) reported that one time early weeding at 25 days after crop emergence resulted in 70% yield increase of common bean compared to no weeding. In line with this result, Tilahun (1998) also reported at least two early weeding at 15 and 30 days after crop emergence, resulted in efficient weed management and significantly higher crop yields. Likewise, Tenaw *et al.* (1997) reported increase in grain yield with an increase in weeding frequencies in common bean. Therefore, early removal of weeds had a significant contribution to the grain yield increase.

On the other hand, season-long weed interference significantly reduced the grain yield of common bean by 36% as compared to the weed-free check. This was significantly lower than the values obtained from the rest of the weeding frequencies. The low yield in weedy check plots might be the results of weed interference with the crop for sunlight, moisture and nutrients. Prakash *et al.* (2000) found that season-long crop weeds competition reduced the green pod yield of peas. Similarly, Ghadiri and Bayat (2004) stated that an uncontrolled population of weeds reduced yields of Pinto bean by 75%. Furthermore, unrestricted weed growth significantly reduced common bean grain yield by 58% (Mukhtar, 2012) and the yield of white bean by 70% (Malik *et al*., 1993) as compared to weed-free treatment.

3.4.5. Aboveground dry biomass

Aboveground dry biomass was significantly ($p \leq 0.01$) affected by main effects of sites and weeding frequencies but not by the plant spacing (Table 2). Significantly, higher (11593.4 kg ha^{-1}) aboveground dry

Table 6. Grain yield, aboveground dry biomass and harvest index of common bean as influenced by the main effects of sites, plant spacing and weeding frequencies during 2012 main cropping season.

Factors	Grain yield (kg ha^{-1})	Aboveground dry biomass	Harvest index (%)
Sites			
Haramaya	1965.2^{b}	5915.6^{b}	33.4^{a}
Hirna	2984.0^{a}	11593.4^{a}	26.4^{b}
LSD $_{(0.05)}$	128.9	579.6	2.3
Plant spacing			
30 cm × 10 cm	2547.9	8883.1	30.7
30 cm × 15 cm	2392.7	8651.6	29.1
40 cm × 10 cm	2483.2	8728.8	29.9
LSD $_{(0.05)}$	NS	NS	NS
Weeding frequencies			
One weeding by hand-hoeing 2 WAE	2612.2^{ab}	8989.2^{ab}	31.5^{a}
One weeding by hand-hoeing 3 WAE	2492.3^{bc}	8738.4^{b}	30.1^{a}
One weeding by hand-hoeing 4 WAE	2385.1^{c}	8506.9^{b}	29.6^{ab}
Two weeding by hand-hoeing 2 and 5 WAE	2718.8^{a}	9297.8^{ab}	31.3^{a}
Weed-free check	2829.0^{a}	9799.4^{a}	30.8^{a}
Weedy check	1810.2^{d}	7195.2^{c}	26.1^{b}
LSD $_{(0.05)}$	223.3	1003.9	4.0
CV (%)	13.6	17.2	19.9

WAE = weeks after crop emergence; CV = coefficient of variations; LSD = least significant difference; Means followed by the same letters within each column are not significantly different.

biomass was obtained at Hirna (Table 6), which might be due to significantly higher plant height than at Haramaya.

Plants, which were kept weed-free throughout the season, had the maximum (9799.4 kg ha^{-1}) aboveground dry biomass, which was statistically at par with hand-hoed once at two WAE and twice at two and five WAE (Table 6). However, plants that were not weeded throughout the season had the lowest (7195.2 kg ha^{-1}) aboveground dry biomass. This might be due to the situation conducive to weeds to compete with crops. Further, the aboveground dry biomass obtained from plots that were hand-hoed once at three WAE, four WAE and twice at two and five WAE were statistically at par.

The reduction in the aboveground dry biomass due to season-long weed interference was 26.6% compared to season-long weed-free treatment. In line with this, Ahmadi *et al.* (2007) reported that the loss percentage due to increasing weed infestation duration of dry bean biological yield was 97% compared with full-season weed-free plots. Similarly, weeding increased the mean dry matter yield of common bean by 86.4% compared with no weeding during the dry season (Tenaw, 2014).

3.4.6. Harvest index

Harvest index was significantly ($p \leq 0.01$) affected by main effects of sites but not by the plant spacing and weeding frequencies. Significantly, higher (26.5%) harvest index was obtained at Haramaya (Table 6). This might be due to lower total rainfall and lower minimum and maximum temperature during cropping season (Figure 1). Therefore, there was no luxury vegetative growth at Haramaya, which might have helped plants at Haramaya to convert total dry matter into more economic yield.

However, the situation at Hirna was the reverse, which facilitated luxury vegetative growth at the expense of economic yield. Therefore, the harvest index was reduced even though relatively higher grain yield was registered at Hirna, which was not proportional with the respective aboveground dry biomass.

3.5. Economic Feasibility Analysis of Weed Management Practices

Plant spacing had no significant influence but weeding frequencies significantly ($p \leq 0.01$) influenced grain yield (Table 2). Therefore, an economic analysis was performed on the combined results using the partial budget technique as described by CIMMYT (1988). The result of the partial budget analysis has been presented in a tabular form (Table 7).

Table 7. Estimated net benefit data using partial budget analysis for weed management practices in common bean averaged for two sites in 2012 main cropping season.

Plant spacing	Weeding frequencies	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross benefit (ETB ha^{-1})	Variable total cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})
30 cm × 10 cm	W1	2660	2394	18197	2295	15903
	W2	2515	2264	17206	2295	14911
	W3	2442	2198	16702	2295	14407
	W4	2763	2487	18899	2975	15924
	W6	2023	1820	13834	595	13239
30 cm × 15 cm	W1	2557	2302	17493	2195	15298
	W2	2466	2219	16867	2195	14672
	W3	2294	2064	15690	2195	13495
	W4	2666	2399	18236	2875	15361
	W6	1583	1425	10828	495	10333
40 cm × 10 cm	W1	2619	2357	17913	2144	15769
	W2	2495	2246	17069	2144	14925
	W3	2420	2178	16551	2144	14407
	W4	2727	2455	18655	2824	15831
	W6	1811	1630	12390	444	11946

ETB = Ethiopian Birr; Seed rates of 58, 48.3 and 43 kg ha^{-1} were used for 30 cm × 10 cm, 30 cm × 15 cm and 40 cm × 10 cm plant spacing, respectively; Cost of seeds for planting 10.25 ETB kg^{-1};Cost of lobour 43 ETB per person; Sale price of common bean 9 ETB kg^{-1}; Field price of common bean 7.60 ETB kg^{-1}; Cost of harvesting, threshing and winnowing 130 ETB per 100 kg; Packing and material cost 4 ETB per 100 kg and transportation 6 ETB per 100 kg; WAE = Weeks after crop emergence; W = Weeding frequency; W1, W2, W3, are weeding by hand-hoeing at 2, 3 and 4 WAE, respectively; W4 and W6 two weeding by hand-hoeing at 2 and 5 WAE and weedy check, respectively. ETB = 0.0481 USD (August 12, 2015).

The economic analysis revealed that the highest (15924 ETB ha^{-1}) net benefit accrued from the combined use of 30 cm × 10 cm plant spacing and two weeding by hand-hoeing two and five WAE. The benefit gained from this treatment was 54.1% higher than the value obtained from the 30 cm × 15 cm plant spacing under the weedy check.

The highest net benefit from the aforementioned treatment could be attributed to high yield. Furthermore, the low net benefit was attributed to low yield due to weed competition. From the economic point of view, it was obvious that combined use of 30 cm × 10 cm plant spacing and two weeding by hand-hoeing two and five WAE was more profitable than the rest of the treatments.

4. Conclusion

In this experiment, combination of increased weeding frequencies with narrow plant spacing (30 cm × 10) cm decreased weed density and weed dry weight. Early and/or increased weeding frequencies reduced weed competition thus decreased days to flowering and physiological maturity, increased yield attributes and yield. Thus, it can be concluded that the combined use of 30 cm × 10 cm plant spacing and two weeding by hand-hoeing two and five WAE at two and five weeks after crop emergence increased grain yield and economic benefit of common bean. The experiment conducted in this study need to be undertaken over different common bean varieties, locations and cropping systems, and interactions of the recommended practices shall be studied.

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