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Response of haricot bean (*Phaseolus vulgaris* L.) to row spacing and weeding frequencies in Wolaita Zone, Southern Ethiopia

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Abstract

The common bean is the most important legume in Ethiopia for export and as a source of protein. Weed infestation and lack of appropriate row spacing are major factors affecting its growth and yield. However, limited research exists to determine proper weed management and optimum row spacing for improving the yield performance of haricot beans. Therefore, a field experiment was conducted in the Wolaita Zone, southern Ethiopia, to evaluate the influences of variable row spacing and hand-weeding frequencies on the growth and yield of common bean. Treatments consisting of three-row spacing and five weeding frequencies were laid out in a randomized complete block design in a factorial arrangement with three replications. Data on phenology, growth, yield components, seed yield, and weed parameters were collected and analyzed procedurally. The result showed that weeding frequencies had a significant ($p < 0.05$) effect on days to flowering, days to physiological maturity, plant height, leaf area, leaf area index, pod number, seed number, hundred seed weight, total above-ground biomass, grain yield, weed population, weed dry weight, weed control efficiency, and yield loss, while row spacing had a significant effect on leaf area, leaf area index, pod and seed number, grain yield, total above-ground biomass yield, and yield loss. On the other hand, the interaction effect was shown to be significantly different in the weed population only. Three times of hand weeding and the recommended row spacing of 40 cm resulted in the highest grain yields of 2549.6 kg ha-1, 2056 kg ha-1, respectively. The highest net benefit (15415.56 ETB ha-1) was recorded from hand weeding done three times, and the highest marginal rate of return (209.99) was obtained from hand weeding done two times. As a result, for greater economic benefit from haricot bean production in the studied area, twice-hand weeding after two and four weeks of crop emergence with a row spacing of 40cm could be recommended.

Keywords: Grain yield, hand weeding, net return and weed population

Introduction

The origin of the common bean is believed to be in tropical America. However, the crop is cultivated on all continents with the exception of Antarctica (FAO, 1998). The world's leading common bean producers are Brazil, Mexico, the USA, Ethiopia, Uganda, Burundi, Tanzania, Turkey, Argentina, Rwanda, Angola, and Colombia (Gepts, 1998). The crop was introduced into Africa probably by the Portuguese in the 16th century through Sofala (Mozambique), Zanzibar, and Mombasa, from where it was taken to higher altitudes of the interior, including Ethiopia, by slave trading caravans and merchants (Gepts, 1998).

The common bean is the most important legume as a source of protein and an export crop in Ethiopia (Dereje et al., 1995). It contains a considerable amount of protein, is high in lysine, and is a good source of energy, making it a good complement and staple in the diet (Pachico, 1993). In Ethiopia, besides its use as a readily available source of protein for farmers, it is also an important cash crop and export commodity that generates foreign exchange for the country (Dereje et al., 1995). It is predominantly cultivated as a cash crop in the central rift valley, but in other parts, it is a major staple food, supplementing the protein source for the poor farmers who cannot afford to buy expensive animal-sourced protein (CACC, 2002). Furthermore, the crop plays an important role in various cropping systems. The productivity of common bean at a national and regional level is 1.56 and 1.44 t ha-1, respectively (CSA, 2016), which is still below the potential yield for haricot bean of about 3 t ha-1 (EARO, 2004).

This low productivity might be attributed to several factors, such as declining soil fertility, rainfall variability, pest pressure, a shortage of high-yielding elite cultivars, poor agronomic practices, and most importantly, weed management. Weeds are the most underestimated pest in tropical agriculture, influencing human activities more than other crop pests (Blackshaw, 1991). Weeds compete with crop plants for growth factors such as water, nutrients, space, and light, leading to a significant amount of yield reduction, with an estimated amount reaching up to 98% in common beans (Dawit et al., 2011; Amare and Etagegnehu, 2016). The effect of weed competition becomes very critical when it occurs during the early vegetative growth stages of common beans (Blackshaw, 1991). To minimize yield losses due to weed competition, different control measures are being adopted. The spatial arrangement of crop plants, particularly row width and plant spacing, provides a non-chemical means of reducing the impact of weed interference on crop yields (Sunyob et al., 2012). With variations in row and plant spacing, the growth and biomass accumulation of crop plants and weeds vary in common beans (Ghadiri and Bayat, 2004).

Thus, better dominance of crop plants over weeds under close spacing suppresses the growth and development of weeds, while wider spacing allows the presence of more weeds and a higher dry weight (Mengesha et al., 2015). Indeed, adequate weed management at the right time is crucial for maximizing production and productivity. Etagegnehu and Amare (2016) reported that weed density and dry matter significantly increased while crop yield decreased as the duration of weed-crop association increased. Hence, this necessitates determining optimum row spacing and weed control for common bean production at Wolaita Sodo ATVET College in Southern Ethiopia. Thus, this study was initiated with the objectives of determining optimum row spacing and weeding frequency in haricot bean production and suggesting a profitable weeding frequency.

Materials and methods

Description of experimental site

A field experiment was carried out during the main cropping season of 2017–18 on the farmland of the Sodo Agricultural Technical, Vocational, and Educational Training College (ATVET) in Wolaita Sodo, Southern Region of Ethiopia. Geographically, the site is located at an altitude of 1950 meters above sea level at 6°34'N latitude and 37°43'E longitude. The area is with the minimum and maximum temperature of 13.5 and 23 ^{o}C, respectively, and an average annual rainfall of 950 mm. The soil at the test location is nitosol, which has textural classes of sandy clay loam and pH values of 4.9, 0.16%, 0.02%, and 2.22 mg/kg, respectively, for organic carbon, total nitrogen, and accessible phosphorus (Wondimu, 2017).

Treatments and experimental design

Treatments consisted of three row spacings (30, 40, and 50 cm) and five weeding frequencies (once hand weeding at 2 weeks after crop emergency, twice hand weeding at 2 and 4 weeks after crop emergency, three times hand weeding at 2, 4, and 6 weeks after crop emergency, weed free check, and weedy check). The treatments were combined in a factorial arrangement and laid out in a randomized complete block design with three replications. The plot was 3 x 2 m with a total gross area of 6 m2, and the respective numbers of rows for 30, 40, and 50 cm row spacing were 10, 7, and 6.

Materials used and agronomic practices

Haricot bean variety Awassa dume was used for the study, which was released in 2008 by Hawassa Agricultural Research Center. It has a medium seed size, white flowers, an erect type, and a determinate growth habit with a maturity period of 85–90 days and is well adapted to the area, which has rainfall of more than 500 mm during the growing season (Tesfaye, 2015). The experimental field was plowed, pulverized, and leveled to get a smooth seedbed. Seeds were hand-planted by placing two seeds per hill, and after emergence, seedlings were thinned to maintain the desired plant density per plot. The recommended rate of NPS was applied at the rate of 100 kg/ha at planting, while 50 kg/ha urea was applied in a split, with the first half at planting and the remaining second half near flowering. The crops inter and intra spacing was 40 cm and 10 cm, respectively. Diseases and insect damage were visually monitored during the crop-growing season. Insignificant disease and insect damage have occurred, and no corrective measures have been taken.

Data ccollection and mmeasurements

Crop data

Plant height (cm): It was measured for ten randomly selected plants per plot at physiological maturity from the ground level to the tip of a plant. Leaf area (cm^2) was measured for ten randomly selected plants per plot just before flowering by using a pictorial method where the area of the individual leaf was compared with the predetermined pictorial area. Leaf area index: It was estimated as the ratio of total leaf area to the respective ground area occupied by the crop as described by Marschner (1995).

Yield components and yield

Number of pods per plant (No): It was counted for ten randomly selected plants per plot at physiological maturity. Number of seeds per pod (No): It was counted for ten randomly selected plants per plot at physiological maturity. Hundred seed weight (g): It was measured by counting 100 representative seed samples from each plot and weighing them with a sensitive balance. Total above-ground biomass yield (kgha-1): It was determined by weighing all plants in central rows, excluding border rows, and then converted into kg/ha. Grain yield (kgha-1): It was manually harvested from a plot net area and converted to kg/ha after adjusting the moisture content to 10%. Harvest index (%):

It was calculated from grain yield and total above-ground biomass yield and estimated as:

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Total above ground biomass yield}} \times 100$$

Weed parameters

Weed population (No): It was determined by using a quadrat of 0.5 × 0.5 m thrown randomly at two places from each plot before 15 days of crop harvest and converted into meter per unit area. Weed dry weight (g): It was determined by cutting the above-ground weeds and exposing them for sun-drying at harvest after measuring the weed population. Relative weed density (%): It was estimated from the weedy check plots by placing a quadrat of 0.5× 0.5 m thrown randomly at two spots in each plot before the flowering of the crop and expressed in percentage. Yield loss (%): It was estimated by subtracting the yield from a plot completely free of weeds from the yield of a particular weed treatment divided by the yield of the plot completely free of weeds and multiplying by 100 using the formula (Milberg and Hallgren, 2004).

$$\text{Yield loss} = \frac{\text{Yield of plot completely free from weeds- particular weed treatment}}{\text{Yield of plot completely free from weeds}} \times 100$$

Weed control efficiency (WCE): was calculated as weed dry weight in weedy check minus weed dry weight in a particular weed control treatment over weed dry weight in weedy check using the formula (Singh et al., 2013):

$$\text{WCE} = \frac{\text{weed dry weight in WC- weed dry weight in a WCT}}{\text{Weed dry weight in WC}} \times 100$$

Where WC = Weedy check treatment,

WCT = A particular weed control treatment

Partial budget analysis

The economic feasibility was conducted using the partial budget analysis method (CIMMYT, 1988). All cost and price estimations were done in Ethiopian Birr. Net income (NI) was determined as the difference between gross income and variable costs (Babatunde, 2004). Total Revenue (TR): Estimated as TR = Adjusted Yield (AY) x Field Price of the Grain, the gross field benefits for each treatment are calculated by multiplying the field price by the adjusted yield. Net Revenue (NR): Computed as NR = TR - total variable cost (TVC) (labor cost, seed cost, and transport cost), i.e., it is calculated by subtracting the total costs that vary from the gross field benefits for each treatment. Marginal rate of return (MRR): In order to use the marginal rate of return (MRR) as a basis for weed management practices, the minimum acceptable rate of return was set at 100% (CIMMYT, 1988). Thus, the marginal rate of return (MRR) was calculated as the marginal net benefit (i.e., the change in net benefits) divided by the marginal cost (i.e., the change in costs), expressed as a percentage.

Statistical data analysis

The collected 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), and interpretations were made in accordance with Gomez and Gomez (1984). Whenever the effects of the treatments were found to be significant, the means were compared using the Least Significant Differences (LSD) test at a 5% level of significance.

Results and discussion

Growth parameters

Plant height

Analysis of variance showed that plant height was significantly ($P<0.05$) different due to the effect of weeding frequencies (Table 1). The tallest plant height (18.5 cm) was recorded at weedy check, followed by weeding once with a mean plant height of 16.5 cm. The shortest plant height (10.9 cm) was measured on weed-free plots. The tallest plant height at weedy treatments was likely due to the elongation of inter-nodes (‘etiolating’) as a result of insufficient radiation penetration, overshading, and self-shading. Due to increased plant density from crop plants and emerging weeds within proximity of each other, the internodes lengthen and the stems become elongated due to a phototropism reaction of plants in response to light stimulus. This was also

Journal of Science and Inclusive Development Vol. 5, No. 1, DOI: 10.20372/jsid/2023-109

confirmed by Kahalil et al. (2010) and Amanullah et al. (2010), who indicated that plants were taller with increased plant density in reaction to enhance competition among plants for light. In contrast, Etagegnehu and Amare (2016) reported that plants attained taller heights in frequently weeded plots as compared to weedy treatments. On the other hand, interrow spacing and its interactions with weeding frequencies did not have a significant effect on plant height.

Leaf area

Analysis of variance revealed that row spacing resulted in significant differences P<0.05 on leaf area. The greatest leaf area (35.91 cm2) was measured at a row spacing of 50 cm, followed by a row spacing of 40 cm, with a mean leaf area of 32.90 cm2. The least leaf area (32.17 cm2) was recorded at a row spacing of 30 cm (Table 1). Higher plant density due to the narrowing of row spacing resulted in the obvious production of smaller leaves with a smaller leaf area, which might attribute to the low red (R): far-red (FR) solar radiation ratios. Thus, a low R/FR ratio during light periods reduces leaf size by inhibiting leaf growth at high plant densities (Dzormeku et al., 2007). This result is consistent with Beruktawit's (2012) findings, which stated that plants produced more leaf area with wider row spacing and vice versa.

The weed-free treatment had the greatest leaf area (42.35 cm2), followed by three times hand weeding with a mean leaf area of 34.87 cm2. The least leaf area (27.06 cm2) was observed from the weedy check treatment (Table 2) (P<0.05). This probably suggests that weed competition for resources impaired normal growth and development, as evidenced by the production of smaller leaf areas from weedy treatments. Dzormeku et al. (2007) and Lamptey et al. (2015) discovered that weedy treatments resulted in smaller leaf areas in soybeans.

Leaf area index

Analysis of variance revealed that row spacing resulted in significant differences in leaf area index (Table 1). Generally, LAI tended to decline with the widening of row spacing. The highest LAI (5.81) was recorded at a row spacing of 30 cm followed by a row spacing of 40 cm with a mean LAI of 5.24. The lowest LAI (4.83) was obtained from a row spacing of 50 cm (Table 1). This distinct difference in LAI was proportional to plant density which illustrated that LAI values were proportionally increased with increasing plant density levels indicating that common beans cultivated at narrower row spacing had a greater LAI and vice versa. Similarly, Bavec

(2002) pointed out that the LAI was influenced by several factors, such as genotype, plant density, climate, and soil fertility. Plant density remained the most important factor with a profound effect on LAI. Thus, a greater LAI at high plant densities illustrates that more plants per unit area result in more soil surface coverage and better light interception within certain optimum limits of plant density. This result is also in agreement with the findings of Gezahegn et al. (2016), who reported a relationship between LAI and plant density, indicating that the LAI increased as plant density increased.

On the other hand, the greatest LAI (8.38) was obtained from a weed-free plot followed by hand weeding three times with a mean LAI of 5.85. The lowest LAI (3.10) was achieved from weedy check plots. This indicates that weeds are a permanent constraint on crop plant growth and development by competing for nutrients, space, and light and exerting a lot of harmful effects if left uncontrolled. This result was also in agreement with the findings of Amini et al. (2013) and Fitsum et al. (2016), who stated that lower LAI on weedy treatments as compared to weeded treatments.

Table 1. Plant height, leaf area, and LAI as affected by row spacing and weeding frequencies during the 2017 main cropping season in Wolaita zone, Southern Ethiopia

Row spacing (cm)	Plant height (cm)	Leaf area (cm^2)	LAI
30	14.95	32.17[b]	5.81[a]
40	14.82	32.90[ab]	5.24[ab]
50	14.28	35.91[a]	4.83[b]
LSD (0.05)	NS	3.04	0.74
Weeding Frequencies			
Once hand weeding	16.45[b]	30.42[cd]	4.04[c]
Twice hand weeding	15.33[c]	33.59[bc]	5.10[b]
Three-time hand weeding	12.28[d]	34.87[b]	5.85[b]
completely weed free	10.93[e]	42.35[a]	8.38[a]
Weedy check	18.45[a]	27.06[d]	3.10[c]
LSD (0.05)	1.12	3.93	0.96
CV (%)	7.9	12.1	18.8

Means followed by different letters within a column are significantly different at 5% probability level, NS=not significant

Yield components and yield

Pod per plant

As row spacing spread, there was a trend for the number of pods per plant to increase. The highest number of pods per plant (20.6) was recorded at a row spacing of 50 cm, followed by a row spacing of 40 cm, with a mean number of pods per plant of 18.3 (Table 2) (P<0.05). The lowest number of pods per plant (17.3) was obtained with a row spacing of 30 cm. A higher number of pods per plant in wider row spacing might be attributed to less competition due to a lower number of plants per unit area. This finding is consistent with Babaeian et al. (2012), who discovered that wider row spacing increased the number of pods per plant.

The highest number of pods per plant (22.9) was obtained from weed free check plots, followed by three times weeding with a mean number of pods per plant of 22.0. The lowest number of pods per plant (13.1) was counted from weedy check treatments (Table 2). A higher number of pods per plant in weed-free checks 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 vigorous leaves might have aided the crop to improve its photosynthetic efficiency, which might have nourished a large number of pods. This finding is supported by the findings of Costa et al. (2013) and Esmaeiladeh and Aminpanah (2015), who found that the number of pods produced per plant in common beans varied significantly due to weed management, with weed-free plants producing more pods than weedy plants.

Number of seeds per pod and hundred seed weight

An analysis of variance revealed that row spacing, weeding frequency, and their interactions had no effect on the number of seeds per pod. Weed free yielded the highest hundred seed weight (HSW) (43.2 g), followed by three times weeding yielding a mean HSW of 42.6 g. The lowest HSW (25.2 g) was obtained from weedy plots (Table 2) (P<0.05). The higher HSW from weed-free treatments may be due to less competition for growth resources, which may have allowed the plants to gain access to available nutrients and better translocation of photosynthates from source-to-sink, resulting in higher photosynthate accumulation in the seeds. On the other hand, the reduction of HSW on weed-infested plots might be attributed to intensified competition of weeds with crop plants that reduced the translocation of photosynthates from source (the leaf) to sink (the seed) during grain filling. This result was in line with the finding of Cheema and Akther (2005), who found that HSW increased with reduced weed infestation and vice versa in mung beans. Moreover, a similar result was reported on chickpeas by Rashid et al. (2009) where weed interferences decreased HSW.

Table 2. Number of pods per plant, seeds per pod and HSW as affected by row spacing and weeding frequencies during 2017 main cropping season in Wolaita zone

Row spacing (cm)	Number of pods per plant	Number seeds per pod	HSW (g)
30	17.3[b]	4.1	36.7
40	18.35[ab]	4.3	36.7
50	20.6[a]	4.4	37.6
LSD	3.1	NS	NS
Weeding frequencies			
Once hand weeding	17.6[b]	4.1	35.6[c]
Twice hand weeding	17.9[b]	4.5	38.6[bc]
Three-time hand weeding	22.0[a]	4.7	42.6[ab]
Completely weed free	22.9[a]	5.0	43.2[a]
Weedy check	13.1[c]	2.9	25.2[d]
LSD (0.05)	4.0	NS	4.3
CV (%)	22.5	7.6	12.1

Means followed by different letters within a column are significantly different at 5% probability level, NS=not significant, HSW= Hundred seed weight

Total above ground biomass

Total above-ground biomass (5282 kg/ha) was achieved from row spacing of 40 cm followed by row spacing of 50 cm with a mean grain yield of 5066 kg/ha. The lowest biomass yield (4574 kg/ha) was recorded at a row spacing of 30 cm (table 3) ($P<0.05$). Increasing row spacing from 30 to 40 cm resulted in a biomass gain of about 15.48%, while increasing to 50 cm resulted in a biomass gain of 10.75%. This result suggested that row spacing deviations of less than or greater than 40cm had a negative impact on biomass yield. Total above-ground biomass is a function of numerous interacting environmental and genetic factors, and its production is directly related to

Journal of Science and Inclusive Development Vol. 5, No. 1, DOI: 10.20372/jsid/2023-109

potential growth and development factors such as solar radiation, water supply, availability of mineral nutrients, and crop management practices. From the viewpoint of total biomass, the row spacing of 40 cm performed better than other levels. This demonstrated that subjecting plants to optimal row spacing increased their ability to capture resources, which was reflected in their increased biomass production. Weed-free plots produced the highest biomass yield (8092 kg/ha), followed by three-time weeding, which produced a mean biomass yield of 6754 kg/ha. The lowest biomass yield (1435 kg/ha) was achieved from weedy plots. When all weeding treatments were compared to a weed-free control, the biomass yield loss for weeding once was 140.69%, 58.84% for weeding twice, and 19.81% for weeding three times. This result was consistent with Fistum et al. (2016)'s finding that biomass yield was lower on weedy treatments compared to weeded treatments.

Yield

The highest yield (2056 kg ha-1) was obtained with a row spacing of 40 cm, followed by 50 cm with a yield of 1825 kg/ha. The lowest grain yield (1773 kg/ha) was achieved with a row spacing of 30cm (Table 3) ($P<0.05$). Reduction of row spacing from 40 to 30 cm resulted in a yield loss of 15.96% while widening of row spacing from 40 to 50 cm resulted in a 12.66% yield loss. Crop yield is a function of several factors and processes such as the amount of light intercepted by the canopy, the metabolic efficiency of plants, and the translocation efficiency of photosynthates from leaves to economic parts. Differences in row spacing caused a profound impact on common bean yield by affecting yield and yield components. Balanced growth and development of plants need an optimum plant density because optimum density enables plants' efficient utilization of available nutrients, soil water, and better light interception, coupled with other growth factors (Gustavo et al., 2006). Narrow row spacing above an optimum level intensifies competition for solar radiation, soil nutrients, and soil moisture. On the other hand, wider row spacing exhibited lower grain yield per unit area, which might be attributable to a lower number of plants per unit area.

Thus, alteration of row spacing above or below the recommended range results in yield reduction, presumably due to severe competition or underutilization of resources. The highest yield (3177 kg/ha) was recorded from weed-free check followed by weeding three times with a mean yield of 2549 kg/ha. The lowest yield (563 kg/ha) was obtained from weedy treatments. When all weeded plots were compared with weed-free plots, there was a yield loss of 166.30% for weeding once, 63.68% for weeding twice, 24.64% for weeding three times, and 464.12% for weedy check plots. Similarly, Tenaw et al. (1997) found that increasing weeding frequencies increased yield in common beans. Hence, the early removal of weeds had a significant contribution to the grain yield increase. In line with the findings, Mengesha et al. (2015) reported that season-long weed interference significantly reduced the yield of the common bean by 36% as compared to the weed-free check.

Harvest index

The Harvest index is the physiological efficiency and ability of a crop for converting the total dry matter into economic yield. Analysis of variance showed that row spacing, weeding frequencies, and their interactions did not result in significant differences (Table 3). Similarly, Naim and Ahmed (2011) reported that row spacing did not cause significant differences in harvest index in common beans.

Table 3. Total above ground biomass, yield and harvest index as affected by row spacing and weeding frequencies in 2017 main cropping season in Wolaita zone, Southern Ethiopia

Row spacing (cm)	Total above ground biomass yield (kg/ha)	Yield (kg/ha)	Harvest index (%)
30	4574[b]	1773[b]	41.19
40	5282[a]	2056[a]	38.31
50	5066[ab]	1825[ab]	39.22
LSD (0.05)	534	238	NS
Weeding frequencies			
Once hand weeding	3362[d]	1193[d]	36.34
Twice hand weeding	5226[c]	1941[c]	37.56
Three-time hand weeding	6754[b]	2549[b]	37.74
completely weed free	8092[a]	3177[a]	39.31
Weedy check	1435[e]	563[e]	46.92
LSD (0.05)	690	308	NS
CV (%)	14.4	16.9	31.4

Means followed by different letters with in a column are significantly different at 5% probability level, NS=not significant

Journal of Science and Inclusive Development Vol. 5, No. 1, DOI: 10.20372/jsid/2023-109

Weed parameters and controlling efficiency

Weed dry weight

The weedy check produced the highest weedy dry weight (18.67 g/m2), which was followed by weeding once with a mean weed dry weight of 13.92 g/m2). Three times hand weeding resulted in the lowest weed dry weight (2.62 g/m2) (table 4). This could be because hand-weeding removed newly emerged weed species, which contributed to the low weed dry matter. Moreover, the reduction in weed dry weight with increasing weed frequency was likely due to the periodic removal of weeds from the field, which stops the continuous growth of weeds. Similarly, Mengesha et al., (2015) and Etagegnehu and Amare (2016) reported that greater weed dry weight was recorded from weedy treatment while lower weed dry weight was observed in treatments of two- and three-time weeding. On the other hand, row spacing and its interactions with weeding frequencies did not have a significant effect on weed dry weight (Table 4).

Weed control efficiency

Weed control efficiency results showed the tendency of increasing as weeding frequency increased. The greatest WCE (100) was observed at completely weed-free treatment followed by weeding three with a mean WCE of 85.47. The lowest WCE (25.83) was measured at one hand weeding (Table 4). This finding indicated that after completely weed-free treatment, weeding three times was efficient as compared to the rest treatments. Once hand weeding was less efficient as compared to twice and three times hand weeding. Thus, increasing weeding frequency enabled the controlling of late and newly emerging weeds in the field. In line with this work, Amare and Etagegnehu, (2016) reported that more frequent weeding resulted in higher weed control efficiency. On the other hand, row spacing and its interactions with weeding frequencies did not have a significant effect on weed control efficiency.

Yield loss

Yield loss in response to row spacing ranged from 29.21 to 44.87%, with the highest yield loss (44.87%) recorded at a row spacing of 50 cm. The lowest yield loss (29.21%) was recorded at a row spacing of 30 cm (table 4) ($P<0.05$). Reduction of row spacing probably minimized the competition effect of late and new emerging weeds by suppression of crop plants.

Thus, the result showed that higher yield loss at wider row spacing implied greater yield loss due to weed competition. In general, yield loss due to weeding frequency ranged from 18.51 to 81.87% (Table 4). The weedy check resulted in the greatest yield loss (81.87%), followed by weeding once with a mean yield loss of 59.51%. The lowest yield loss (18.51%) was recorded from weeding three times. The greatest yield loss from weed control was most likely due to weeds remaining in the field, which exacerbated the severity of weed competition with crop plants for growth resources. Similarly, Singh et al. (2000) and Costa et al. (2013) showed that unchecked weed growth caused a yield loss of 90.9% in chickpea.

Table 4. Weed dry weight, weed control efficiency and yield loss as affected by row spacing and weeding frequencies in 2017 main cropping season in Wolaita Zone, Southern Ethiopia

Row spacing (cm)	Weed dry weight (g/m^2)	Weed Control Efficiency (%)	Yield loss (%)
30	6.81	60.01	43.92^{b}
40	8.46	55.72	29.21^{b}
50	8.63	54.17	44.87^{a}
LSD (0.05)	NS	NS	9.93
Weeding frequencies			
Once hand weeding	13.92^{b}	25.83^{d}	59.51^{b}
Twice hand weeding	4.64^{c}	71.89^{c}	36.77^{c}
Three times hand weeding	2.62^{cd}	85.47^{b}	18.51^{d}
Weedy check	18.67^{a}	0.00e	81.87^{a}
completely weed free	0.00d	100a	0.00e
LSD (0.05)	3.07	7.30	12.83
CV (%)	39.88	13.34	33.76

Means followed by different letters with in a column are significantly different at 5% probability level, NS=not significant

Partial budget analysis

The partial budget analysis revealed that the effect of three times hand weeding and weedy check treatments resulted in the highest (15415.56) and lowest (4059.69 Eth. birr ha-1) net benefits (Table 5). The highest net benefit from three-hand weeding could be due to better weed control efficiency and lowest yield loss as compared to other treatments. The lowest net benefit from weedy check treatment could be attributed to high weed competition, which resulted in maximum yield loss. The highest (11663.48 ETB ha-1) and lowest (9270.61) net benefits were

Journal of Science and Inclusive Development Vol. 5, No. 1, DOI: 10.20372/jsid/2023-109

obtained from the effect of 40 and 30-cm row spacing, respectively. The highest net benefit from 40 cm row spacing could be due to the highest yield response of the crop as compared to other treatments. Similarly, Mengesha et al. (2015) found that two hand-hoeing weedings with a plant spacing of 30x10 cm yielded the greatest net benefit. Twice-hand weeding yielded the highest marginal rate of return (209.98%).

Table 5. Profitability of weed management practices in common bean in 2017 cropping season

Row Spacing	Weeding frequency	AY (kgha^{-1})	AJY (kg ha^{-1})	GB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
	WC	575.39	517.86	5696.46	1618.041	4078.419	0
	W1	958.48	862.63	9488.93	3922.466	5566.465	64.57
	W2	1727.03	1554.33	17097.63	6868.841	10228.79	158.24
30cm	W3	2385.6	2147.04	23617.44	9632.024	13985.42	135.95
	WF	3216.38	2894.75	31842.25	19348.29	12493.96	-15.35
	WC	548.76	493.89	5432.79	1513.697	3919.094	0
	W1	1597.4	1437.67	15814.37	4926.29	10888.08	204.21
	W2	2471.85	2224.67	24471.37	8048.97	16422.4	348.67
40cm	W3	2721.29	2449.17	26940.87	10130.96	16809.91	18.61
	WF	2940	2646	29106	18828.1	10277.9	-75
	WC	566.07	509.46	5604.06	1422.501	4181.559	0
	W1	1022.38	920.14	10121.54	3848.859	6272.681	86.18
	W2	1623.32	1460.99	16070.89	6516.162	9554.729	123.05
50cm	W3	2541.75	2287.58	25163.38	9712.023	15451.36	184.51
	WF	3373.5	3036.17	33397.87	19429.91	13967.96	-15.26
Row spacing	30	1772.576	1595.322	17548.54	8277.932	9270.611	68.68
	40	2055.86	1850.28	20353.08	8689.603	11663.48	99.298
	50	1825.404	1642.868	18071.55	8185.891	9885.658	75.696
Weeding frequency	WC	563.4067	507.07	5577.77	1518.08	4059.691	0
	W1	1192.753	1073.48	11808.28	4232.538	7575.742	118.32
	W2	1940.733	1746.663	19213.3	7144.658	12068.64	209.9867
	W3	2549.547	2294.597	25240.56	9825.002	15415.56	113.0233
	WF	3176.627	2858.973	31448.71	19202.1	12246.61	-35.2033

AY=Average yield, AJY= Adjusted yield, GB= Gross benefit, TVC= Total variable cost, NB=Net benefit, MRR= Marginal rate of return W1=One weeding, W2=Two weeding, W3=Three weeding , WF = completely weed WC= Weedy check, ETB=*Ethiopian Birr. Cost of each treatment was indicated in appendix 5. Adjusted yield was adjusted by 10%.*

Conclusions

This study evaluated the effect of row spacing and weeding frequencies on phenology, growth, yield components, yield, and weed control of common bean. The effect of row spacing on grain yield and biomass were substantially different, with the highest yield and biomass being attained at a row spacing of 40 cm and the lowest yield and biomass being at a row spacing of 30 cm. Significant differences were detected due to the effect of weeding frequencies on biomass and grain yield, where the highest biomass and grain yield were recorded from weed-free plots and the lowest biomass and grain yield were achieved from weedy plots. Analyses of variance revealed that weeding frequencies resulted in significant differences in weed dry weight, with the weedy check yielding the highest weed dry weight and three times weeding yielding the lowest. Analysis of variance showed that weed control efficiency has significantly differed in response to weeding frequencies, with the greatest weed control efficiency observed at weeding three times and the lowest weed control efficiency seen at weeding once. Economic analysis also confirmed that twice hand weeding after 2 and 4 weeks crop emergency and use of 40 cm row spacing yielded maximum marginal rates of returns of 209.98% and 99.29%, respectively. As a result, twice hand weeding after 2 and 4 weeks of crop emergence and row spacing of 40cm provided the greatest economic benefit.

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Conflict of interest

Authors declare no conflict of interest.

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