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Effect of plant spacing and weeding frequency on weed infestation, yield components and yield of mung bean [*Vigna radiata* (L.) Wilczek] at Kosokol, Bench Sheko zone, South Western Ethiopia

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Abstract
Improper spacing and weed competition are one of the important production constraints that cause reduction in potential yield of mung bean. Therefore, an experiment was conducted at Bench Sheko Zone, South Western Ethiopia, during the 2019 main cropping season to evaluate the effect of plant spacing and frequency of weeding on weeds, yield components and yield of mung bean. There were 18 treatments comprising combination of three plant spacing (30 cm x 10 cm, 30 cm x 15 cm and 40 cm x 10 cm) and six weeding frequency [one hand weeding and hoeing at 2 weeks after crop emergence (WAE), one hand weeding and hoeing at 3 WAE, one hand weeding and hoeing at 4 WAE, two hand weeding and hoeing at 2 and 5 WAE, weed free check and weedy check]. The treatments were arranged in factorial combination in a randomized complete block design with three replications. Results showed the highest weed control efficiency obtained from interaction of 30cm x 10cm plant spacing and twice hand weeding and hoeing at 2 and 5 WAE. Significantly higher number of pods per plant (20.38) and seeds per pod (11.68) was obtained from weed free check. The highest grain yield 1412.9 kg $ha^{-1}$and harvest index 42.94% were obtained from weed free check. However, the economic analysis revealed that the highest net benefit of 34965.2 ETB ha^{-1} were obtained from combined use of 30 cm × 10 cm plant spacing and twice hand weeding and hoeing at 2 and 5 WAE. Thus, it is suggested that planting Rasa variety of mung bean at 30 cm x 10 cm plant spacing 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 at study area.

Keywords: grain yield, net benefit, spacing, weed control efficiency and weed dry weight

1. Introduction

Mung bean [*Vigna radiata* (L) Wilczek] commonly known as green gram is one of the most important pulse crops, grown in the tropical and subtropical areas of the world (Khan *et al.*, 2012) [19]. It is an important wide spreading, herbaceous and annual legume pulse crop cultivated mostly by traditional farmers (Ali *et al.*, 2010) [3]. At present, mung bean cultivation spreads widely in Africa, South America, Australia and in many Asian countries (Gebre, 2015) [15]. The crop is characterized by fast growth under warm conditions, low water requirement and excellent soil fertility enhancing crop through nitrogen fixation (Yagoob and Yagoob, 2014) [35].

In Ethiopia, mung bean is a recently introduced and mostly grown by smallholder farmers under the drier marginal environmental conditions and the production capacity is lower than other pulse crops (Asrate *et al.*, 2012) [7]. Its production is limited by several constraints of which weeds and lack of proper spacing are major causes.

Growth and development of weeds can be suppressed by plant spacing and weeding frequency. Closely spaced crop provides good smothering potential on growth and development of weeds due to less availability of space for growth and development. 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) [26]. Improper spacing reduced the yield of mung bean up to 20 to 40% (Mondal, 2007) [24].

Weed management is an important key factor for enhancing the productivity of mung bean, as weeds compete for nutrient, water, light and space with crop plants during early growth period

(Chaudhari et al., 2016) [16]. Uncontrolled weed populations can substantially reduce the yield of mung bean from 65.4 to 79.0% (Dungarwal *et al*., 2003) [12]. Tamang *et al*. (2015) [32] reported that the increasing number of weeding significantly increase grain yield of mung bean. However, there is limited information on the inter and intra row spacing, weeding frequency and their response on weed population dynamics, yield and yield components of mung bean at South Western Ethiopia.

Therefore the objectives of this study were;

- To evaluate the effect of plant spacing and weeding frequency on the yield and yield component of mung bean.
- To determine the economic feasibility of different weed management practices in mung bean.

2. Materials and Methods

2.1. Description of study area

The Experiment was conducted at Mizan Agricultural Technical Vocational Education and Training College farm site at Kosokol located in Bench Sheko Zone of the South Nations, Nationalities and Peoples Regional (SNNPR) state (Figure 1) in 2019 main cropping season.

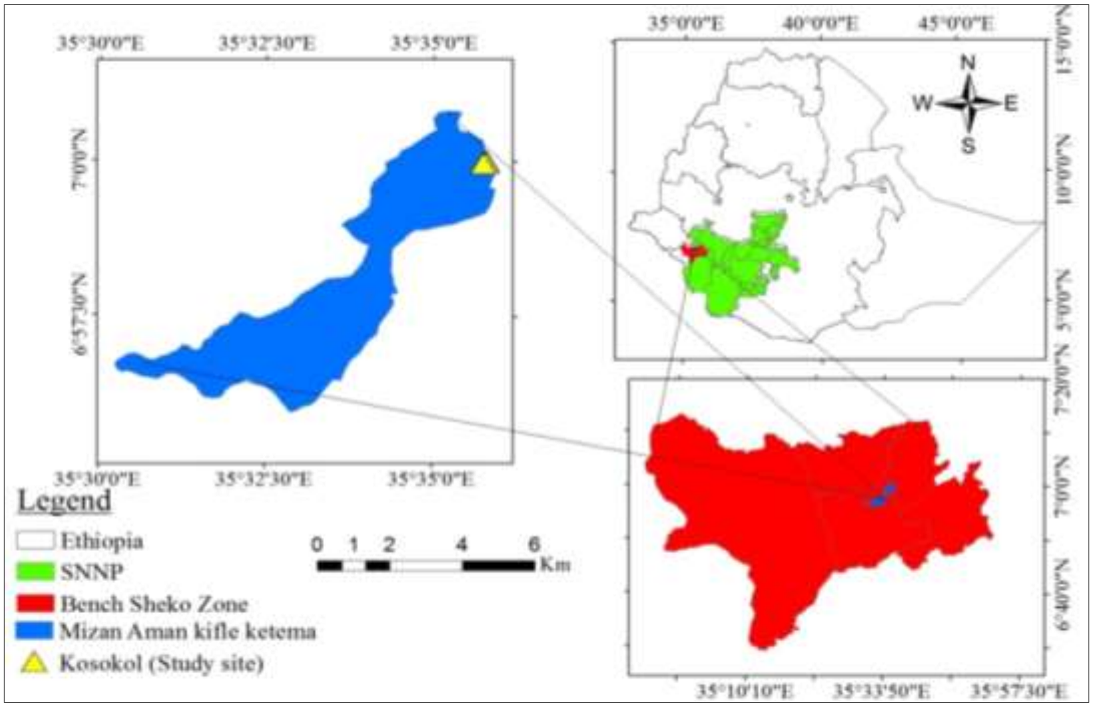

Fig 1: Map showing the experimental site of Kosokol, Bench Sheko zone, south western Ethiopia

The Zone is located 561 km Southwest of Addis Ababa and 830 km from Hawassa, the regional center. The experimental site is located at 06°59'46.5"N latitude, 35°35'46.7"E longitude, and altitude of 1366 meters above sea level. The rainfall in the area is characterized by bimodal distribution pattern with the main rainy season (June-August) and small rainy season (March-May). The annual rainfall distribution in the zone ranges from 400 mm to 2000 mm and the annual average temperature ranges from 15.1 to 27.5°C (BMZFED, 2018) [8].

2.2. Data collected

The weed flora present in the experimental field was recorded from weedy check plots by placing a quadrat (0.25 m × 0.25 m) randomly at two spots in each plot. The weeds that were easy to identify was recorded in the field and the species were categorized into their botanical families at 20 days after crop emergence, 55 days after crop emergence and at harvest. The weed density were recorded by throwing a quadrat (0.25 m × 0.25 m) randomly at two places in each plot at 20 days after crop emergence, 55 days after crop emergence and at harvest (about 15 days before the expected harvest time), and the weed count were done at each time and recorded. The weeds falling within the quadrat were counted and were expressed as number of weed per meter square. Weed dry weight was determined by cutting the weeds falling within the quadrat near the ground at 20 days after crop emergence, 55 days after crop emergence and at harvest immediately after taking observation on weed count. The samples were sun dried for 4 days and thereafter were placed in an oven at 65°C temperatures till a constant weight and subsequently their dry weight was measured. The dry weight was expressed in g m-2. Weed control efficiency was calculated from weed control treatments in controlling weeds and using the following formula:

WCE = (WDC-WDT)/WDC X100

Where; WCE = Weed Control Efficiency, WDC = weed dry matter in weedy check, WDT = weed dry matter in a particular treatment

Days to 50% flowering was recorded as the number of days from planting to when 50% of the plants in net plot area showed first flower through visual observation. Days to physiological maturity was recorded as the number of days from planting to when 90% of the plants in a net plot area showed yellowing of

pods. Plant height was measured with a meter as the height of 10 randomly taken and pre tagged plants from the ground level to the apex of each plant at the time of physiological maturity from the net plot area. The total number of pods in 10 randomly pre tagged plants in each net plot area was counted at harvest and expressed as the average number of pods per plant.
The total number of seeds in ten randomly taken pods from the net plot area was counted and divided by total number of pods to find the number of seeds per pod. Thousand seed weight was determined by taking the weight of thousand randomly sampled seeds from the total harvest from each net plot area and adjusted to 10% moisture level. Grain yield was measured by taking the weight of the grains threshed from the net plot area and then converted to kg ha-1 after adjusting the grain moisture content to 10%.At physiological maturity; from the destructive rows the above ground dry biomass of randomly taken ten plants was measured after drying till a constant weight. For obtaining the total above ground dry biomass, the dry biomass per plant thus obtained was multiplied by the total number of plants per net plot area and was converted into kg ha-1.Harvest index was calculated by dividing grain yield per net plot area by the total above ground dry biomass yield per net plot area and was multiplied by 100 as follows:

HI (%) = (Grain yield)/(Biological yield) X100

Yield loss was determined as a percentage of the difference between weeded plots (complete weed free) and yield in a particular treatment.

YL = (Y1-Y2)/Y1 X100

Where; YL = Yield loss, Y1 = Yield in complete weed free, Y2 = Yield in a particular treatment.

2.3 Data analysis
Data on weed density, weed dry biomass, crop phenology, yield components and yield were subjected to analysis of variance using SAS software version 9.1 (SAS Institute, 2003) [29] and interpretations were made following the procedure described by Gomez and Gomez (1984) [17]. Whenever the effects of the factors (treatments) were found to be significant, the means were compared using the Least Significant Differences (LSD) test at 5% level of significance.

2.4. Partial budget analysis
As described by CIMMYT (1988) [11] the partial budget analysis was done to determine the economic feasibility of the weed management practices. It was calculated by taking into account the additional input and labor 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) [11]. The total cost that varied in the labor cost where hand weeding is required was identified. 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 parameters
3.1.1. Weed flora
The experimental field was infested with different types of weed species includes broad leaf, grasses and sedges weeds (Table 1). Those weeds were recorded under fifteen species and six families.

Table 1: Weed flora recorded in the experimental field of mung bean in 2019 main cropping season

Weed species	Family	Life Form (Category)
Ageratum conyzoides L.	Asteraceae	Annual (Broad leaf)
Cassia pumila Lam.	Fabaceae	Annual (Broad leaf)
Chromolaena odorata L. R.M. king & H. Rob	Asteraceae	Perennial (Broad leaf)
Chrozophora rottleri Klotzsch.	Euphorbiaceae	Annual (Broad leaf)
Commelina diffusa L.	Commelinaceae	Annual (Broad leaf)
Commelina forskaolii Vahl.	Commelinaceae	Annual (Broad leaf)
Cynodon dactylon (L.) Pers.	Poaceae	Perennial (Grass)
Cyperus iria L.	Cyperaceae	Annual (Sedge)
Cyperus brevifolius Rottb.	Cyperaceae	Annual (Sedge)
Dichanthium annulatum (Forsk.) Stapf.	Poaceae	Annual (Grass)
Eclipta alba (L.) Hassk.	Asteraceae	Annual (Broad leaf)
Emilia sonchifolia (L.) DC. Ex Wight.	Asteraceae	Annual (Broad leaf)
Euphorbia thymifolia L.	Euphorbiaceae	Annual (Broad leaf)
Malvastrum coromandelianum (L.) Garcke	Malvaceae	Annual (Broad leaf)
Setaria glauca (L.) P. Beauv.	Poaceae	Annual (Grass)

3.1.2. Weed density (number of weeds m^{-2})
3.1.2.3. Weed density at 55 DAE
Significantly the highest weed density (386.67 m^{-2}) was recorded from interaction effect of 30 cm x 15 cm plant spacing with weedy check which was followed by the combination of 40 cm x 10 cm spacing with weedy check (Table 3). Among weedy checks, when row spacing was wider the weed infestation become higher and had shown significant difference at (P<0.05). The significant reduction in weeds densities with the decrease in row spacing under all the weeding frequency as well as weedy checks indicated that under closer spacing, non-availability of enough space to the weeds might have become a limiting factor resulting in lower densities compared to wider spacing.

Table 2: Interaction effect of plant spacing and weeding frequency of mung bean on weed density at 55 DAE in 2019 main cropping season

	Plant spacing		
Weeding frequency (W)	30cm x 10cm	30cm x 15cm	40cm x 10cm
One hand weeding and hoeing at 2 WAE	198^{d-f}	248^{c}	212.67^{c-e}
One hand weeding and hoeing at 3 WAE	175.67^{e-g}	223.67^{c}	173.33^{e-g}
One hand weeding and hoeing at 4 WAE	157.33^{f-h}	193.33^{d-f}	138.33^{g-i}
Two hand weeding and hoeing at 2 and 5 WAE	89.33^{j}	116.33^{h-j}	100^{ij}
Weed free check	0^{k}	0^{k}	0^{k}
Weedy check	255.67^{c}	386.67^{a}	327.67^{b}
LSD (0.05)	46.5		
CV (%)	16.84		

Where; WAE = Weeks after crop emergence, LSD = Least significant difference, CV = Coefficient of variations; Means in the same columns and rows followed by the same letters are not significantly different at 5% level of significance.

On the other hand, while comparing the interaction of weeding frequency with row spacing, the lowest weed density was obtained from interaction effect of narrow plant spacing of 30 cm x 10 cm with twice hand weeding and hoeing at 2 and 5 WAE which was statistically at par with combination of 40 cm x 10 cm and 30 cm x 15 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE next to combination of all plant spacing with weed free check. This result indicated that as availability of lesser space for weed development, better crop competition for development resources, crop growth, early space covering, might have effectively controlled the weeds. This result is in line with the findings of Faruq *et al*. (2018) [13] who observed that the highest weed density of mung bean was recorded in weedy check and the lowest was observed in weed free treatments.

3.1.2.4 Weed density at harvest (number of weeds m^{-2})

Significantly the highest weed density (432.33 m^{-2}) was recorded from combination of 30 cm x 15 cm spacing with weedy check than all other interactions (Table 4). This might be due to infestation of weeds in the wider spacing. This result is in line with Getachew *et al*. (2017) [17] who reported that uncontrolled weed infestation resulted in significantly higher weed density in cowpea.

The lowest weed density (93.33 m^{-2}) was obtained from the interaction effect of 30 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE next to interaction of all plant spacing with weed free check. This might be due to competitive advantage of crop over weeds; the later emerging weeds were suppressed by taller crop plants more under closer spacing, thus resulting in reduced total weed density.

Table 3: Interaction effect of plant spacing and weeding frequency of mung bean on weed density at harvest in 2019 main cropping season

	Plant spacing		
Weeding frequency (W)	30cm x 10cm	30cm x 15cm	40cm x 10cm
One hand weeding and hoeing at 2 WAE	205.67^{de}	246.33^{cd}	212.33^{c-e}
One hand weeding and hoeing at 3 WAE	175.33^{ef}	209.67^{c-e}	171.33^{ef}
One hand weeding and hoeing at 4 WAE	148.33^{fg}	189.67^{d-f}	136.33^{fg}
Two hand weeding and hoeing at 2 and 5 WAE	93.33^{g}	107.67^{g}	94.67^{g}
Weed free check	0^{h}	0^{h}	0^{h}
Weedy check	265.33^{c}	432.33^{a}	324.67^{b}
LSD (0.05)	56.7		
CV (%)	20.41		

Where; WAE = Weeks after crop emergence, LSD = Least significant difference, CV = Coefficient of variations; Means in the same columns and rows followed by the same letters are not significantly different at 5% level of significance.

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

3.1.3.2. Weed dry weight at 55 DAE

The highest weed dry weight (502.67 g m-2) was obtained from the combination of 30 cm x 15 cm spacing with weedy check than all the other treatment (Table 5). It was followed by interaction of 40 cm x 10 cm spacing with weedy check which was statistically similar with combination of 30 cm x 10 cm with weedy check. This result is in line with the observation of Chaudhari *et al*. (2016) [16] who stated that among the different treatments the highest dry weight of weeds was recorded under weedy check treatment.

The lowest weed dry weight at 55 DAE (74.67 gm-2) was recorded in the interaction of 30 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE which was statistically at par with the combination of 30 cm x 15 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE, 40 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE and 30 cm x 10 cm spacing with one hand weeding and hoeing at 4 WAE. This reduction of weed dry weight might be due to lower weed density than the other treatments (Table 2)

Table 4: Interaction effect of plant spacing and weeding frequency of mung bean on weed dry weight (g m^{-2}) at 55 DAE in 2019 main cropping season

	Plant spacing		
Weeding frequency (W)	30cm x 10cm	30cm x 15cm	40cm x 10cm
One hand weeding and hoeing at 2 WAE	270.67^{e}	291.33^{de}	337.33^{cd}
One hand weeding and hoeing at 3 WAE	178^{gh}	204.67^{fg}	258^{ef}
One hand weeding and hoeing at 4 WAE	118^{ij}	147.67^{hi}	198^{gh}
Two hand weeding and hoeing at 2 and 5 WAE	74.67^{j}	93.33^{ij}	97.33^{ij}
Weed free check	0^{k}	0^{k}	0^{k}
Weedy check	372^{bc}	502.67^{a}	425.33^{b}
LSD (0.05)	55.94		
CV (%)	17.01		

Where; WAE = Weeks after crop emergence, LSD = Least significant difference, CV = Coefficient of variations; Means in the same columns and rows followed by the same letters are not significantly different at 5% level of significance.

3.1.3.3. Weed dry weight at harvest (g m-2)

The highest weed dry weight (643.67 g m-2) was obtained from the interaction effect of 30 cm x 15 cm with weedy check which was statistically similar with the combination of 40 cm x 10 cm spacing with weedy check (584.33 g m-2) and 30 cm x 10 cm spacing with weedy check (571.33 g m-2) (Table 6). The result was in line with the findings of Gaganpreet *et al*. (2009) [14] who reported that, at harvest all the treatments recorded significantly less dry matter production of weeds than the unweeded control. The result indicates that the availability of more space for the weeds under wide spacing resulted in significantly higher weed density than the other spacing and resulted in higher weed dry weight. Likewise, Nano and Janmejai (2018) [25] reported that the higher weed dry weight in weedy check was due to higher weed density that provided an opportunity to the weeds to compete vigorously for nutrients, space, light, water and carbon dioxide resulting in higher biomass production.

The lowest weed dry weight at harvest (160 g m-2) was obtained from the interaction of 30 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE next to interaction effect of all plant spacing with weed free check. The possible reason of reducing the dry weight of weeds might be due to closely spaced crop resulted in good smothering potential on growth and development of weeds. Similar results were also reported by Chaudhari *et al*. (2016) [9]. The lowest weed dry weight recorded from twice hand weeding and hoeing at 2 and 5 WAE under all plant spacing was due to lowest weed density resulted from controlling of the weed. In line with this result, Chaudhari *et al*. (2016) [9] reported that minimum weed dry weight in different weed management treatment with weed free condition might be due to effective weed control obtained under hand hoeing at early crop growth stage, which resulted into the lowest weed counts and finally reduced the total dry weight of weeds at harvest.

Table 5: Interaction effect of plant spacing and weeding frequency of mung bean on weed dry weight (g m^{-2}) at harvest in 2019 main cropping season

	Plant spacing		
Weeding frequency (W)	30cm x 10cm	30cm x 15cm	40cm x 10cm
One hand weeding and hoeing at 2 WAE	298.33^{de}	524.33^{b}	448.33^{c}
One hand weeding and hoeing at 3 WAE	311.33^{de}	417.33^{c}	321.33^{d}
One hand weeding and hoeing at 4 WAE	284.33^{de}	332.33^{d}	299.67^{de}
Two hand weeding and hoeing at 2 and 5 WAE	160^{g}	239.33^{ef}	202.67^{fg}
Weed free check	0^{h}	0^{h}	0^{h}
Weedy check	571.33^{ab}	643.67^{a}	584.33^{ab}
LSD (0.05)	75.26		
CV (%)	14.48		

Where; WAE = Weeks after crop emergence, LSD = Least significant difference, CV = Coefficient of variations; Means in the same columns and rows followed by the same letters are not significantly different at 5% level of significance.

3.1.4. Weed control efficiency (%)

The highest weed control efficiency (100%) was obtained from interaction effect of all plant spacing with weed free check which was followed by the interaction effect of 30 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE (72.3%) and 40 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE (65.66%) (Table 7). However these were statistically at par with the interaction effect of 30 cm x 15 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE (61.72%). The lower weed density and lower weed dry biomass recorded from interaction of 30 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE resulted in higher weed control efficiency. Likewise, Chaudhari *et al*. (2016) [16] reported that, the highest weed control efficiency at harvest was recorded under weed free treatment.

On the other hand the lowest weed control efficiency was obtained from the combination effect of 30 cm x 15 cm plant spacing with one hand weeding and hoeing at 2 WAE next to interaction of all plant spacing with weedy check which was statistically at par with interaction of 40 cm x 10 cm spacing with one hand weeding and hoeing at 2 WAE (Table 7). When we compare plant spacing in all weeding frequency, one hand weeding and hoeing at 2 and 3 WAE recorded statistically higher weed control efficiency under narrow spacing of 30 cm x 10 cm than wider spacing of 30 cm x 15 cm. This might be due to more competition offered by mung bean for growth resources and early space covering.

Table 6: Interaction effect of plant spacing and weeding frequency of mung bean on weed control efficiency in 2019 main cropping season

	Plant spacing		
Weeding frequency (W)	30cm x 10cm	30cm x 15cm	40cm x 10cm
One hand weeding and hoeing at 2 WAE	47.32^{d}	17.51^{g}	22.98^{fg}
One hand weeding and hoeing at 3 WAE	45.58^{d}	32.97^{ef}	44.59^{de}
One hand weeding and hoeing at 4 WAE	49.64^{cd}	47.34^{d}	48.28^{d}
Two hand weeding and hoeing at 2 and 5 WAE	72.3^{b}	61.72^{bc}	65.66^{b}
Weed free check	100^{a}	100^{a}	100^{a}
Weedy check	0^{h}	0^{h}	0^{h}
LSD (0.05)	12.1		
CV (%)	15.33		

Where; WAE = Weeks after crop emergence, LSD = Least significant difference, CV = Coefficient of variations; Means in the same columns and rows followed by the same letters are not significantly different at 5% level of significance.

3.2. Crop parameters
3.2.1. Phenology and growth
3.2.1.1. Days to 50% plant flowering
The highest days to 50% plant flowering or late flowering (55 days) was recorded under weedy check than other treatments (Table 8). However, it was statistically similar with one hand weeding and hoeing at 4 WAE. The reason for delayed or late flowering of mung bean in weedy check was due to weed infestation during growth of mung bean than the other treatments. The shading of mung bean by the canopy of weed in weedy check reduced the penetration of sunlight and prolongs the vegetative growth and resulted in late flowering. In line with this result, Sunday and Udensi (2013) [31] identified that the plants in not weeded plots took the highest time to reach 50% flowering in cowpea. Similarly Nano and Janmejai (2018) [25] also reported that delayed days to flowering in faba bean was recorded under weedy check than the other treatments.

The lowest days to 50% plant flowering or earlier flowering (51.22 days) was recorded under weed free check and it is statistically similar with twice hand weeding and hoeing at 2 and 5 WAE. The possible reason for earlier flowering of mung bean in weed free check than the other treatment was due to lower weed infestation in weed free treatment.

3.2.1.2. Days to 90% physiological maturity
The highest days to 90% physiological maturity (77.78 days) was recorded under weedy check than the other treatment (Table 8). The delayed maturity of mung bean in weedy check was due to the shading effect of crop plants by weeds that reduced sunlight interception and caused delayed days to physiological maturity. Likewise, Sunday and Udensi (2013) [31] reported that the plants under not weeded plots took the highest time to reach 90% physiological maturity in cowpea. Similarly, Mitiku *et al*. (2012) [22] reported that with increase in the density of Parthenium, the duration required by the common bean plants to reach physiological maturity was prolonged.

Plants, which were kept weed free throughout the season, had the lowest (73.89 days) days to 90% physiological maturity, which was statistically at par with days to 90% physiological maturity obtained from plants that were hand weeded and hoed twice at two and five WAE (74.56 days) (Table 8). The reason of earlier maturity of mung bean under weed free treatment was due to exposure of crop to sunlight that minimizes vegetative growth of crop and resulted in early maturity of crops.

There was no significant effect of plant spacing on days to 90% physiological maturity. This result was in agree with Abayneh (2018) [1] who reported that interaction effect of inter and intra row spacing of mung bean did not show significant effect on days to 90% physiological maturity.

Table 7: The main effect of plant spacing and weeding frequency of mung bean on days to 50% flowering, days to 90% maturity and plant height in 2019 main cropping season

Treatment	Days to 50% flowering	Days to 90% physiological maturity	Plant height (cm)
Plant spacing			
30cm x 10cm	53.22	75.72	31.71
30cm x 15cm	53.00	75.89	31.33
40cm x 10cm	53.05	75.78	31.49
LSD (0.05)	NS	NS	NS
Weeding frequencies			
One hand weeding and hoeing at 2 WAE	53.00^{bc}	76.00^{ab}	33.30^{ab}
One hand weeding and hoeing at 3 WAE	53.11^{bc}	76.33^{ab}	31.61^{bc}
One hand weeding and hoeing at 4 WAE	54.11^{ab}	76.22^{ab}	30.47^{bc}
Two hand weeding and hoeing at 2 and 5 WAE	52.11^{cd}	74.56^{bc}	29.10^{c}
Weed free check	51.22^{d}	73.89^{c}	29.06^{c}
Weedy check	55^{a}	77.78^{a}	35.53^{a}
LSD (0.05)	1.17	1.86	3.55
CV (%)	2.32	2.56	11.76

Where; WAE = Weeks after crop emergence, NS = Non-significant, LSD = Least significant difference, CV = Coefficient of variations; Means followed by the same letters within each column are not significantly different at 5% level of significance.

3.2.1.3. Plant height (cm)

The highest plant heights (35.53 cm) was obtained from weedy check treatments than the other which was statistically at par with one hand weeding and hoeing at 2 WAE (33.3 cm) (Table 8). The increment of mung bean heights under non-weeded treatments might be due to higher competition of crops with weeds in order to exposing their canopy to sunlight. This result is in agreement with the report of Getachew *et al*. (2017) [17] who observed that increase in plant height of cowpea in presence of severe weed interference can be due to intense competition between weeds and crop plants and their desire to get light energy. Nano and Janmejai (2018) [25] also reported that the plants in weedy check plots attained significantly higher height than others weed management practices.

The lowest plant height (29.06 cm) was recorded under weed free check than the other treatment. The possible reason of lowering height of mung bean under weed free treatment was due to the absence of competition with weeds and rather than increasing the height the crop produced large number of branches. Plant spacing was not significantly affected plant height of mung bean. In line with this result, Ahmed *et al*. (2010) [2] reported that plant spacing had no significant effect on plant height of groundnut.

3.2.2. Yield components and yield

3.2.2.1. Number of pods per plant

The highest number of pods per plant (14.4) was recorded under wider plant spacing of 30 cm x 15 cm than the other treatments and the lowest number of pods per plant (12.76) which was statistically at par with 40 cm x 10 cm plant spacing was obtained under narrow spacing of (30 cm x 10 cm) (Table 9). The possible reason of increase in the number of pods per plants in wider plant spacing might be due to less competition between plants on resources that causes vigorously growth of plants. Moreover, plant grew vigorously on wider spacing might produce more branches and nodes that resulting in high number of pods per plant. This result was in line with Asaye *et al*. (2018) [6] who reported that the highest number of pods per plant (26.73) was obtained from 50 × 15 cm inter- and intra-row spacing, while the lowest number of pods per plant (7.53) was found at 20 × 5 cm spacing in mung bean. Furthermore, in agreement with this result, Zaher et al. (2014) [38] reported that higher spacing indicates higher number of pods per plant on mung bean. Yadav *et al*. (2014) [34] also reported that a significant difference due to the main effects of plant spacing where the maximum number of pod per plant [34] was observed at 30 cm × 10 cm spacing followed by 40 cm x 10 cm spacing and minimum number of pods per plant [30] was observed at 20 cm ×10 cm on mung bean. Comparable results were reported in field pea by Yayeh *et al*. (2014) [36] where they found the highest number of pods per plant in wider row spacing as compared to closer spacing. Likewise Getachew *et al*. (2017) [17] also reported on cowpea that number of pods per plants was higher in wider plant spacing due to vigorously growth of crop in wider spacing.

Table 9: The main effect of plant spacing and weeding frequency of mung bean on number of pods per plant and number of seeds per pod in 2019 main cropping season

Treatment	Number of pods per plant	Number of seeds per pod
Plant spacing		
30cm x 10cm	12.76^{b}	8.57^{b}
30cm x 15cm	14.40^{a}	9.73^{a}
40cm x 10cm	13.86^{ab}	9.22^{ab}
LSD (0.05)	1.14	0.77
Weeding frequencies		
One hand weeding and hoeing at 2 WAE	12.18^{d}	9.00^{cd}
One hand weeding and hoeing at 3 WAE	13.97^{c}	9.52^{bc}
One hand weeding and hoeing at 4 WAE	11.04^{d}	8.22^{d}
Two hand weeding and hoeing at 2 and 5 WAE	17.27^{b}	10.21^{b}
Weed free check	20.38^{a}	11.68^{a}
Weedy check	7.17^{e}	6.43^{e}
LSD (0.05)	1.61	1.09
CV (%)	12.36	12.4

Where; WAE = Weeks after crop emergence, LSD = Least significant difference, CV = Coefficient of variations; Means followed by the same letters within each column are not significantly different at 5% level of significance.

Plants which were kept weed free throughout the growing season had the highest number of pods per plant (20.38) than all the other treatments. It was followed by twice hand weeding and hoeing at 2 and 5 WAE. However the lowest number of pods per plant (7.17) was recorded under weedy check than all the other treatments. The result indicated that, number of pods per plant was increased as weed infestation decreased. The higher number of pods per plant in weed free check might be due to the absence of competition for moisture, nutrient and light from weeds as the plots were kept weed free throughout the cropping season. Similar results were reported by Zaher et al. (2014) [38] where they observed that, the increasing number of weeding significantly increased number of pods per plant. Akter et al. (2013) [28] also reported that higher number of pods per plant was found in three stages weeding than no weeding treatment.

3.2.2.2. Number of seeds per pod

The highest number of seeds per pod (9.73) was recorded under wider spacing of 30 cm x 15cm than the other treatments (Table 9). However it was statistically similar with 40cm x 10 cm spacing while the lowest number of seeds per pod (8.57) was recorded under narrow plant spacing of 30 cm x 10 cm than the other treatment and it was statistically comparable with that of 40 cm x 10 cm spacing. The highest number of seeds per pod in wider plant spacing might be due to less competition between plants on resources in wider plant spacing that caused maximum pods length and resulted in maximum number of seeds per pod in these plots. This result was in line with the report of Almaz *et al*. (2016) [4] who stated that the widest inter and intra-row spacing (12 × 50 cm) gave a significantly higher number of seeds per pod than the other. Mebrate *et al*. (2017) [20] also reported that, number of seeds per pod increased from 6.8 to 10.1 as row spacing increased from 10 cm to 40 cm. Similarly, Yayeh *et al*. (2014) [36] also stated that maximum number of seeds per pod in wider row spacing than closer row spacing in field pea.

On the other hand, the highest number of seeds per pod (11.68) was obtained from weed free check than the other treatment. It was followed by twice hand weeding and hoeing at 2 and 5 WAE which was statistically at par with one hand weeding and hoeing at 3 WAE. While the lowest number of seeds per pod (6.43) was obtained from weedy check. The highest number of seeds per pod under treatments kept weed free throughout the season was due to the absence of competition for nutrient, moisture and light from the weeds and the vigorous leaves of mung bean might have helped to improve the photosynthetic efficiency of the crop that supported large number of seeds per pod. In line with this, Akter et al. (2013) [28] reported that higher number of seeds per pod was found in three stages weeding than no weeding treatment. Similar results were also reported by Zaher *et al*. (2014) [38] where they observed that, the increasing number of weeding significantly increased number of seeds per pod.

3.2.2.3. Thousand seed weight (g)

The highest number of thousand seed weight (34.06 g) was obtained from wider spacing of 30 cm x 15 cm which was statistically at par with 40 cm x 10 cm spacing (Table 11). While the lowest thousand seed weight of mung bean (30.33 g) was recorded under narrow spacing of 30 cm x 10 cm however it was statistically at par with the seed weight obtained from 40 cm x 10 cm plant spacing. The possible reason for the highest thousand seed weight recorded under wider plant spacing of 30 cm x 15 cm might be due to availability of more space for better light interception, more nutrients availability and moisture for crop or grain development as compared to narrow plant spacing of 30 cm x 10 cm. This finding is in line with the study of Kabir and Sarkar (2008) [18] who reported that the highest 1000 seed weight was observed at 40 cm × 30 cm spacing than narrow spacing of 20 cm × 20 cm in mung bean. Similarly Abayneh (2018) [1] also stated that the highest thousand seed weights (35.44 g) were recorded for seeds sown at the intra and inter row spacing of 15 cm and 40 cm whereas the lowest thousand seed weights (33.04 g) were recorded at the intra and inter row spacing of 5 cm and 25 cm.

On the other hand, the highest number of thousand seed weight of mung bean (36.22 g) was recorded under treatments which were kept weed free throughout the season. However it was statistically at par with thousand seed weight obtained from plants that were twice hand weeded and hoed at 2 and 5 WAE (34.89) and it was followed by one hand weeding and hoeing at 3 WAE. The increment of thousand seed weight in weed free treatments might be due to reduced competition between weeds and crop for growth resources, which might have enhanced the availability of nutrients and better translocation of photosynthates from source to sink, and resulted in higher accumulation of photosynthates in the seeds. These results were in line with the result of Zaher et al. (2014) [38] who stated that increasing number of weeding significantly increased 1000 seed weight. Akter et al. (2013) [28] also reported that thousand seed weight of mung bean was increased as frequency of weeding was increased.

The lowest number of thousand seed weight (28.44 g) was recorded under non-weeding treatment throughout the season whereas it was statistically at par with thousand seed weight obtained from one hand weeding and hoeing at 2 WAE and one hand weeding and hoeing at 4 WAE. The reason of lowered seed weight might be due to competition of weeds with crops. In agreement with these findings, Peer *et al*. (2013) [27] observed lowest number of hundred seed weight of soybean in weedy check plots.

3.2.2.4. Aboveground dry biomass (kg ha-1)

The highest aboveground dry biomass yield (3309.2 kg ha-1) was obtained from weed free check which was statistically similar with one hand weeding and hoeing at 2 WAE, one hand weeding and hoeing at 3 WAE and twice hand weeding and hoeing at 2 and 5 WAE (Table 10). The increment of aboveground dry biomass in these treatments might be due to the crop plants utilized the resources more efficiently than the other treatments and resulted in higher number of pods per plant (Table 9). In line with this result, Akter et al. (2013) [28] reported that the highest biological yield (4.70 t ha-1) was obtained in plants from two stage weeding and the lowest biological yield (2.67 t ha-1) was recorded from no weeding. Similarly, Nano and Janmejai (2018) [25] observed that the highest aboveground dry biomass was obtained from weed free check than the other treatments in faba bean. On the other hand, the significantly lower aboveground dry biomass yield (2118.7 kg ha-1) was obtained from weedy check. This might be due to severe competition for growth resources resulting in lower availability of nutrients for the crop thus causing reduction in number of branches thereby low husk yield. Similar findings were found by Zaher et al. (2014) [38] where they stated that increasing number of weeding significantly increased biological yield.

3.2.2.5. Grain yield (kg ha-1)

The highest grain yield (1142.31 kg ha-1) was recorded under plant spacing of 30 cm x 10 cm. However it was statistically at par with grain yield (1096.89 kg ha-1) obtained from 40 cm x 10 cm spacing (Table 10). This might be due to lower weed dry weight and higher weed control efficiency recorded under narrow spacing of 30 cm x 10 cm (Table 6 and 7) and also due to higher crop density per hectare obtained from 30 cm x 10 cm spacing. An agreement with this result, Arce *et al*. (2009) [5] showed that areas with higher plant densities might have a competitive advantage over weeds due to fast canopy development. In contrast to this the lowest grain yield (1040.83 kg ha-1) was obtained from wider spacing of 30 cm x 15 cm. It might be due to lower density of the crop per hectares recorded under wider plant spacing, and the highest weed dry biomass and lowest weed control efficiency caused lower grain yields under wider spacing. In line with this, Mebrate *et al.* (2017) [20] also reported that grain yield was decreased as plant spacing increased up to a certain optimum limit. Kabir and Sarkar (2008) [18] also reported that 30 cm ×10 cm plant spacing gave higher yield (1046.00 kg ha-1) and 20 cm × 20 cm space gave lower yield (750.50 kg ha-1) of mung bean. Similarly, Asaye *et al.* (2018) [6] found that the highest adjusted grain yield of 1882.67 kg ha-1 was obtained at interaction of 40 × 10 cm, while the lowest adjusted grain yields of 1401.5 kg ha-1 was obtained at interaction of 50 × 15 cm inter and intra row spacing

Table 8: The main effect of plant spacing and weeding frequency of mung bean on aboveground dry biomass (kg ha^{-1}), grain yield (kg ha^{-1}) and harvest index (%) in 2019 main cropping season

Treatment	Above ground dry biomass (kg/ha)	Grain yield (kg/ha)	Harvest INDEX (%)
Spacing			
30cm x 10cm	3060.5	1142.31^{a}	36.71
30cm x 15cm	2955.6	1040.83^{b}	34.18
40cm x 10cm	3040.0	1096.89^{ab}	35.24
LSD (0.05)	NS	67.33	NS
Weeding frequencies			
One hand weeding and hoeing at 2 WAE	3179.3^{ab}	1107.24^{c}	34.83^{c}
One hand weeding and hoeing at 3 WAE	3224.9^{ab}	1251.16^{b}	38.97^{b}
One hand weeding and hoeing at 4 WAE	2999.9^{b}	936.88^{d}	31.27^{c}
Two hand weeding and hoeing at 2 and 5 WAE	3280.1^{ab}	1358.55^{a}	41.71^{ab}
Weed free check	3309.2^{a}	1412.90^{a}	42.94^{a}
Weedy check	2118.7^{c}	493.34^{e}	22.53^{d}
LSD (0.05)	289.44	95.23	3.94
CV (%)	10.01	9.09	11.62

Where; WAE = Weeks after crop emergence, NS = Non-significant, LSD = Least significant difference, CV = Coefficient of variations; Means followed by the same letters within each column are not significantly different at 5% level of significance

Plants which were kept weed free throughout the season had the highest (1412.9 kg ha^{-1}) grain yield, which was statistically at par with grain yield obtained from twice hand weeding and hoeing at 2 and 5 WAE (1358.55 kg ha^{-1}). The possible reason for higher yields under these treatments were due to higher weed control efficiency resulted in better growth and development leads to developing higher yield components. Therefore the higher number of pods per plant, seeds per pod and thousand seed weight (Table 9 and 11) might have contributed to the significantly higher grain yield in these treatments. Similar results were obtained by Tamang *et al.* (2015) [32] who reported that increase in grain yield with an increase in weeding frequency of green gram. Chhodavadia *et al.* (2012) [10] also found that the lowest dry weight of weed, highest weed control efficiency and highest grain yield was recorded under two hand weeding and weed free than weedy treatment. On the other hand, plants which were not weeded throughout the season had the lowest grain yield (493.34 kg ha^{-1}) than all other treatments. The lowest grain yield in weedy check was as a result of intense weed competition that resulted in lower number of pods per plant, seeds per pod and lower thousand seed weight finally reduced the yields. The higher weed dry biomass and lower weed control efficiency also resulted in yield reduction of mung bean in these treatments.

3.2.2.6. Harvest index (%)

The highest harvest index (42.94%) was obtained from treatments which were kept weed free throughout the season, which was statistically at par with the harvest index obtained from twice hand weeding and hoeing at 2 and 5 WAE (41.71%) (Table 10). The highest harvest indexes from these treatments were due to higher ability of a crop plant to convert the dry matter into economic yield. Likewise Zhu *et al.* (2010) [39] reported that partitioning efficiency (harvest index) is determined by the amount of biomass energy allocated to vegetative vs. reproductive structures. Similar results were also reported by Getachew *et al.* (2017) [17], who reported that highest harvest index of cowpea obtained in weed free check. The lowest harvest index (22.53%) was obtained from weedy check than all the other treatments. In line with this, Zaher et al. (2014) [38] also reported that harvest index were lower in weedy check treatment.

3.2.2.7. Yield loss (%)

As comparing weed management practices with each other’s, the highest yield loss (65.36%) was observed in weedy check plots over weed free check than the other treatments, which was followed by one hand weeding and hoeing at 4 WAE (Table 11). The highest yield loss observed in weedy check was due to weed infestation throughout the season in these treatments. In agreement with this result, Dungarwal *et al.* (2003) [12] reported that weed infestation throughout the crop life cycle resulted in about 65.4 to 79.0% reduction in potential grain yield of mung bean.

Table 9: The main effect of plant spacing and weeding frequency of mung bean on thousand grain weight (g) and yield loss (%) in 2019 main cropping season

Treatment	Thousand seed weight (g)	Yield loss (%)
Spacing		
30cm x 10cm	30.33[b]	20.37
30cm x 15cm	34.06[a]	25.37
40cm x 10cm	32.17[ab]	23.17
LSD (0.05)	2.18	NS
Weeding frequencies		
One hand weeding and hoeing at 2 WAE	31.22[cd]	21.75[c]
One hand weeding and hoeing at 3 WAE	32.56[bc]	11.52[d]
One hand weeding and hoeing at 4 WAE	29.78[cd]	33.65[b]
Two hand weeding and hoeing at 2 and 5 WAE	34.89[ab]	5.53[de]
Weed free check	36.22[a]	0[e]
Weedy check	28.44[d]	65.36[a]
LSD (0.05)	3.08	7.05
CV (%)	10.01	32.04

Where; WAE = Weeks after crop emergence, NS = Non-significant, LSD = Least significant difference, CV = Coefficient of variations; Means followed by the same letters within each column are not significantly different at 5% level of significance.

Similarly, Yadav and Sing (2005) [33] found that, about 69% mung bean grain yield reduction was estimated due to weed infestation. These results were in line with the result of Getachew *et al*. (2017) [17] who reported that higher yield reduction was recorded in weedy checks than the other treatments due to weed infestation. The lowest yield loss (5.53%) was recorded from twice hand weeding and hoeing at 2 and 5 WAE due to less infestation of weed in these treatments. However it was statistically at par with the yield loss observed in one hand weeding and hoeing at 3 WAE (11.522%). Yield losses in one hand weeding and hoeing at 4 WAE was higher than the yield lost in one hand weeding and hoeing at 2 WAE. This indicates that, late weeding results in crop losses, particularly if it is carried out after the critical period of weed competition.

3.3. Partial budget analysis

The partial budget analysis result using the partial budget procedure CIMMYT (1988) [11] was done due to grain yield was significantly influenced by plant spacing and weeding frequency. The result in Table 12 of this study showed that the treatment combinations of all plant spacing with weed free check had maximum (10010 ETB ha-1) total variable cost. This was followed by the treatment combinations of all plant spacing with twice hand weeding and hoeing at 2 and 5 WAE (2860 ETB ha-1). The highest cost of these treatments than in the other treatments were due to the difference in the cost payed for manual weeding.

Table 10: Effect of plant spacing and weeding frequency of mung bean on partial budget analysis in 2019 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})
30cm x 10cm	W1	1182.87	1064.58	31937.4	1430	30507.4
	W2	1285.74	1157.17	34715.1	1430	33285.1
	W3	994.35	894.915	26847.45	1430	25417.45
	W4	1400.93	1260.84	37825.2	2860	34965.2
	W5	1429.26	1286.33	38589.9	10010	28579.9
	W6	560.74	504.666	15139.98	0	15139.98
30cm x 15cm	W1	1013.86	912.474	27374.22	1430	25944.22
	W2	1223.67	1101.3	33039	1430	31609
	W3	876.00	788.4	23652	1430	22222
	W4	1324.26	1191.83	35754.9	2860	32894.9
	W5	1384.81	1246.33	37389.9	10010	27379.9
	W6	422.41	380.169	11405.07	0	11405.07
40cm x 10cm	W1	1125.00	1012.5	30375	1430	28945
	W2	1244.07	1119.66	33589.8	1430	32159.8
	W3	940.28	846.252	25387.56	1430	23957.56
	W4	1350.46	1215.41	36462.3	2860	33602.3
	W5	1424.63	1282.17	38465.1	10010	28455.1
	W6	496.87	447.183	13415.49	0	13415.49

Where; ETB = Ethiopian Birr, W1 = One hand weeding and hoeing at two weeks after crop emergence, W2 = One hand weeding and hoeing at three weeks after crop emergence, W3 = One hand weeding and hoeing at four weeks after crop emergence, W4 = Two hand weeding and hoeing at two and five weeks after crop emergence, W5 = Weed free check and W6 = Weedy check.

The highest (38589.9ETB ha-1) gross benefit was obtained under a treatment combinations of 30cm x 10cm plant spacing with weed-free check. This was followed by the treatment combinations of 40cm x 10cm plant spacing with weed-free check (38465.1ETB ha-1) and 30cm x 10cm plant spacing with twice hand weeding and hoeing at 2 and 5 WAE (37825.2 ETB ha-1). The highest gross incomes in these treatments than in the other treatments were due to their higher yield. The lowest (11405.07 ETB ha-1) gross benefit was recorded under the combined treatments of 30cm x 15cm plant spacing with weedy check plots.

The partial budget analysis of mung bean revealed that the highest net benefit (34965.2 ETB ha-1) was obtained from the combined use of 30 cm × 10 cm plant spacing and twice hand weeding and hoeing at 2 and 5 WAE which was followed by the combination of 40 cm x 10 cm spacing with twice hand weeding and hoeing at 2 and 5 WAE (33602.3 ETB ha-1) and 30 cm × 10 cm spacing with one hand weeding and hoeing at 3 WAE (33285.1 ETB ha-1). The highest net benefit obtained from these treatments could be attributed to high yield. Whereas the lowest net benefit (11405.07 ETB ha-1) was obtained from the interaction of 30 cm x 15 cm spacing with weedy check. The low net benefit was attributed to low yield due to weed competition. From the economic point of view, combined use of 30 cm × 10 cm plant spacing and twice hand weeding and hoeing at 2 and 5 WAE was more profitable than the rest of the treatments.

4. Conclusion

The combination of narrow plant spacing (30 cm × 10 cm) with weed free and twice hand weeding and hoeing at 2 and 5 WAE decreased weed density, weed dry weight and increased weed control efficiency. Increased weeding frequency at critical period reduced weed competition accordingly decreased days to flowering and physiological maturity, increased yield components and yield of mung bean. Therefore, it can be concluded that the combined use of 30 cm × 10 cm plant spacing and twice hand weeding and hoeing at 2 and 5 WAE increased grain yield and economically the most feasible practice for rasa variety of mung bean production in the study area. However, since this study was based on only one season and one location, it requires further study over years and location to give conclusive recommendation.

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