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Research Article

THE INTERACTION EFFECT OF WEED FREQUENCY AND INTER-ROW SPACING ON THE YIELD AND YIELD COMPONENTS OF MUNG BEAN (*Vignaradiata L. Wilczek*)

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ABSTRACT. Mung bean is an important pulse crop but, its productivity is low mainly due to a lack of optimum recommendations for plant population and weed management. Therefore, the present study was conducted to determine the effect of inter-row spacing and weed frequency on the yield and yield components of mung bean. The treatments were laid out in a randomized complete block design in a factorial arrangement with three replications. Data on crop phenology and growth, yield, and yield components of mung bean were collected and subjected to ANOVA using SAS version 9.1software. The results of ANOVA revealed that weed density, weed dry weight, weed control efficiency, seed yield, biomass yield, and harvesting index were significantly ($P<0.05$) affected by the interaction effect of inter rows spacing and weeding frequency. The highest seed yield (1536.33kg ha-1) and the highest percent of MRR (3426) with the highest net benefit (82632.70 ETBha^{-1}) was obtained from the interaction of 30 cm inter-row spacing and weed-free check followed by the combination of 30cm and 40 cm inter-row spacing with two times weeding respectively. This indicated that seed yield increased with reduction of weed population at moderate plant spacing. So, it can be concluded that the use of 30 cm inter-row spacing with weed-free check was the most agronomic efficient and economically viable and is recommended as the first option for mung bean production, followed by the combination of 30 cm and 40 cm inter-row spacing with two times weeding frequency as second and third options respectively.

Key words: *Weedy, weed-free, Grain yield, Plant density, Weed frequency*

INTRODUCTION

Mung bean (*Vigna radiata* L.) is an annual herb pulse crop that belongs to the Fabaceae family [1]. It can adapt to a wide range of climatic conditions. The best environment is a tropical climate with temperatures ranging from 25-35ºC and moderate precipitation between 400-550 mm during its life cycle of 60-90 days [2]. Mung bean production in Ethiopia is most suited with clay loam fluvsol, clay eutric fluvisol, and pellic vertisol types of soil with a pH range from 6.3 to 7.2 [3]. The area coverage of mung bean in the global scale is 7.3 million hectares with the productivity of 5.3 million tones [4]. India and Myanmar are the chief mung bean producer countries in the globe each, supplying approximately 30%, followed by China (16%) and Indonesia (5%) [4]. In East Africa, the average on-farm yield of mungbean is estimated to be 0.5 t/ha. In Ethiopia, the annual area coverage and volume of production of mung bean are 48,022.34 ha, and 515,686.55 ku, respectively with a productivity of 10.74 ku/ha [5]

Mung bean is a vital crop in Ethiopia, where it is consumed as food and feed due to its high protein, vitamin, and mineral content. Despite its importance as food and feed, very little attention has been paid to its quantitative and qualitative improvement in Ethiopia [6]; as a result, its production system is constrained by several factors, such as poor selection of bean seeds, poor quality of seeds, soil degradation, poor husbandry practices, postharvest losses, weather variability, grower perception, poor weed and pest management practices, and improper spacing [7]. Among these factors, weeds and improper spacing are the major mung bean production constraints in the study area. According to Jila Timuga District's Agricultural Office [8], inappropriate plant spacing and lack of weed management are bottlenecks in maximizing mung bean production in Ethiopia. As a result, the national average productivity of Mung bean was 1.07 t/ha [5], which is lower than the potential mung bean producer of Myanmar (1.3 t/ha) [9].

Federal Democratic Republic of Ethiopia Ministry of Agriculture [10] disclosed that an inter-row of 30-40 cm was found to be optimum for planting mung beans during the main rainfall season. However, Amhara National Regional State [11] reported that 40 cm inter-row spacing is optimum for planting mung beans. Additionally, Tojora & Mekonnen [12] suggested that planting mung beans at 30 cm x 10 cm plant spacing and twice weeding the crop produced optimum growth and grain yield of mung beans. However, Kanoosh, *et al.* [13] reported that weed-free treatment with 10 cm spacing produced the highest yield (2.256 tons ha^{-1}). Moreover Birhanu *et al.* [14] suggested that planting of mung bean at inter and intra row spacing of 40×10 cm produced the highest grain yield (1882.67 kg ha^{-1}). These conflicting recommendations create confusion for the smallholder farmers. To resolve this ambiguity, conducting localized field trials in the target region can help identify spacing and management practices that best fit local conditions. Therefore, the present experiment was conducted on three inter-row spacing and four weeding frequencies with the major objective of evaluating the effects of weeding frequency and inter-row spacing on the growth, yield, and yield components of mung beans.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted during the 2023/2024 cropping season in the Afar region of Awra district. The experimental site is located at 1246'0.01" N latitude and 4019'59.98" E longitude, with an altitude of 942 m.a.s.l. The area's mean annual rainfall is 810 mm, and the average maximum and minimum annual temperatures are 36°C and 24°C, respectively [15]**.**

Experimental Materials

The present experiment used the Rasa (N-26) variety, which was obtained from the Werer Agricultural Research Centre (WARC) in Ethiopia.

Experimental Design Agronomic Practice

The experiment was laid out in a factorial arrangement using a Randomized Complete Block Design (RCBD) with three replications. Each treatment was allocated a plot size of 3m by 2m ($6m^2$). The distance between blocks and plots was 1 m and 0.5 m, respectively. The field experimental area covered 324.5 m^2, with dimensions of 29.5 m in length and 11 m in width.

Description of Treatment Combination

The total of 12 treatments was the combination of 4 weeding frequencies and 3 inter-row spacing. The choice of weeding frequency and row spacing was based on the recommendation of previous research work for mung beans. That is, Tojora & Mekonnen [12] suggested that planting of mung bean at 30 cm x 10 cm plant spacing and twice weeding the crop produced optimum growth and grain yield; however, Kanoosh, *et al.*[13] reported that weed-free treatment with 10 cm spacing produced the highest yield (2.256 tons ha^{-1}). To balance these contradictory recommendations, the present experiment selected these treatment combinations.

Table 1. *Description of treatment combination used for field experiment*

Treatments	Details of Treatment combination
S1W0	20 cm row spacing +no weeding
S1W1	20 cm row spacing +one times weeding
S1W2	20 cm row spacing +two times weeding
S1W3	20 cm row spacing +weed free whole season
S2W0	30 cm row spacing +no weeding
S2W1	30 cm row spacing + one times weeding
S2W2	30 cm row spacing +two times weeding
S2W3	30 cm row spacing +weed free whole season
S3W0	40 cm row spacing +no weeding
S3W1	40 cm row spacing +one times weeding
S3W2	40 cm row spacing +two times weeding
S3W3	40 cm row spacing +weed free whole season

Data Collected

Data on Phonological growth, and yield component traits were collected from the central rows in each treatment plot and five randomly selected plants for the individual data.

Description of Collected Data

The following phonological, growth and yield and yield component data were collected on plot and plant basis on each experimental unit from net plot area. These traits were Days to 50% flowering, Days to physiological maturity, Plant height (cm)**,** Number of pods per plant**,** Number of seeds per pod, Hundred seed weights (g), Seed yield (kg), Aboveground Biomass yield (kg), Harvest index (HI) (%).

$$HI = \frac{\text{seed yield}}{\text{Biomass yield}} x100$$ [16].

Eqn. 1

Weed Identification

The weed flora present in the experimental field was identified from weedy check plots by placing a quadrant (0.25 m × 0.25 m) in net plot area randomly at two spots in each replication just before flowering of the crop.

Weed density

Weeds were collected by using a quadrant 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.

$$Density\ (D) = \frac{Total\ number\ of\ weeds\ in\ all\ quadrants}{Total\ number\ of\ quadrants\ studied} X\ 100\%$$

Eqn. 2

$$Relative\ density\ (D) = \frac{Total\ number\ of\ individauls\ of\ a\ give\ weed\ species}{Total\ number\ of\ individuals\ of\ all\ the\ weed\ species} X\ 100\%$$

Eqn. 3

Weed control efficiency

Weed control efficiency was calculated from weed control treatments in controlling weeds and using the following formula:

$$WCE\ (\%) = \frac{weed\ dry\ matter\ in\ weedy\ check - weed\ dry\ matter\ in\ a\ particular\ treatment}{weed\ dry\ matter\ in\ weedy\ check} X\ 100\%$$

Eqn. 4

Partial Budget Analysis

The partial budget analysis as described by [17] was sufficient to determine the economic feasibility of the weed management practices.

Data Analysis

After checking the ANOVA assumptions, the collected data were subjected to analysis of variance (ANOVA) using SAS (Statistical Analysis System) version 9.0. Mean separation was carried out using the Least Significant Difference (LSD) at the 5% level of significance [18]. The assumption of ANOVA (normality) was checked by a Normal Q-Q plot using R software version 4.1.1 (R core team, 2013) [19].

RESULTS AND DISCUSSION

Effects of inter-row spacing and weeding frequency on weed Parameters Weed Species composition

Six families of seven weed species comprising five broad-leaved and two grasses were identified on weedy plots. The identified species include Digitaria sanguinalis, Cyperus rotundus L., Lenotis neptifolid, Parthenium hysterophorus, Solanum melongena, Cucumis melo and Trichosanthes kirilowii. Among these species, Digitaria sanguinalis was observed to have the highest relative density (35%), followed by Cyperus rotundus L (28%). Cucumis melo and Trichosanthes kirilowii were the lowest in relative weed density. Weed infestation relative density by Broad leaves and Grass were 71.43% and 28.57% respectively (Table 2). The result agreed with the findings of [20], who reported that among the annual weeds, Parthenium hysterophorus, Digitaria sanguinalis, and Cyperus rotundus L. weeds are the important weed species in the Afar region of Ethiopia.

Table 2. *Weeds species composition and mean relative density of non-weeded plots in 2023*

Common name	Botanical name	Family	Relative density (%)
Crabgrass	Digitaria Sanguinalis	Poaceae	35
Nutgrass	Cyperus rotundus L.	Cyperaceae	28
Clip dagga	Lenotis neptifolid	Lamiaceae	15
Congress grass	Parthenium hysterophorus	Asteraceae	12
Eggplant	Solanum melongena	Solanaceae	4
Cantaloupe	cucumis melo	Cucurbitaceae	3
Chinese cucumber	Trichosanthes kirilowii	Cucurbitaceae	3

Weed density (m^{-2})

The present experiment showed that weed density was significantly influenced by the main effect of inter-row spacing, weeding frequency, and their interaction (Table 3). Significantly, the highest weed density (454.00 m^{-2}) was recorded from the 40 cm inter-row spacing combination with a weedy check compared to all other interactions (Table 2). The reason for the highest weed density for the combination of widest inter-row spacing (40cm) and unwedded conditions could be the lack of weed interruptions, which might have provided adequate and more space for weeds to occupy than did the other narrower inter-row spacing. This result aligns with Getachew *et al.* [21], who reported that significantly higher weed density in cowpeas was obtained from uncontrolled weed infestation. Similarly, this result also agrees with Asfaw E [22], who described that significantly higher weed density in fava beans was obtained from un-weeded plots.

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

The variance analysis showed that the main effects (weeding frequency and inter-row spacing) and their interactions significantly influenced weed dry weight (Table 3). The highest weed dry weight (433.3 g m-^{2}) was obtained from 40 cm inter-row spacing interaction with a weedy check (Table 3). It 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. The result was in line with the findings of Getachew *et al.* [21]; Nano and Janmejai [23], who reported that all the treatments recorded significantly less dry matter production of weeds than the un-weeded control.

Weed control efficiency (%)

The result of the variance analysis showed that both the main effects of weeding frequency and inter-row spacing and their interaction significantly influenced weed control efficiency. The highest weed control efficiency (100%) was obtained from the interaction effect of any inter-row spacing combined with weed-free check, which was followed by the interaction effect of 20 cm inter-row spacing with twice hand weeding (88.32%) and 30 cm inter-row spacing with twice hand weeding (78.18%), these were statistically at par with the interaction effect of 40 cm inter-row spacing with twice hand weeding (74.18%) (Table 3). Likewise, Tojora & Mekonnen [12] 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 40 cm inter-row plant spacing with one hand weeding frequency next to the interaction of all plant spacing with weedy check (Table 3).

Table 3. *Interaction effect of weed frequency and plant spacing on weed density, weed dry weight and weed control efficiency at Awra district in 2022 crop season*

Interaction	WD (m^{-2})	WDW ($g\ m^{-2}$)	WCE (%)
S1W0	292.33c	267.33^{c}	38.36^{g}
S1W1	161.67f	142.33^{f}	67.14^{d}
S1W2	61.670h	50.33^{h}	88.32^{b}
S1W3	0.0000i	0.000^{i}	100.0^{a}
S2W0	365.00^{b}	358.00^{b}	17.21^{h}
S2W1	198.00e	181.67^{e}	58.11^{e}
S2W2	103.33g	94.33^{g}	78.17^{c}
S2W3	0.0000i	0.000^{i}	100.00^{a}
S3W0	454.00a	433.33^{a}	0.000^{i}
S3W1	235.67d	221.33^{d}	48,85^{f}
S3W2	126.00g	111.33^{g}	74.17^{c}
S3W3	0.0000i	0.000i	100.00^{a}
LSD (0.05)	8.67	23.05	4.2
CV (%)	7.47	8.78	3.88

WD= weed density, WDW= weed dry weight, WCE= weed control efficiency, S1W0= Weedy check with 20 cm spacing, S2W0= Weedy check with 30 cm spacing, S3W0= Weedy check with 40 cm spacing, S1W1= one-hand weeding at 30 days after sowing with 20 cm spacing, S2W1= one-hand weeding at 30 days after sowing with 30 cm spacing, S3W1= one-hand weeding at 30 days after sowing with 40 cm spacing, S1W2= two- hand weeding at 30 and 45 days after sowing with 20 cm spacing, S2W2= two- hand weeding at 30 and 45 days after sowing with 30 cm spacing, S3W2= two- hand weeding at 30 and 45 days after sowing with 40 cm spacing, S1W3=Weed-free check with20 cm spacing, S2W3=Weed-free check with30 cm spacing, S3W3=Weed-free check with40 cm spacing, 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.

Phenology and Growth Parameter

Days to 50% plant flowering

The result of the analysis of variance (ANOVA) revealed that days to flowering were significantly ($p \leq 0.01$) affected by the main effects of weeding frequency. In contrast, the effect of inter-row spacing and its interaction with weeding frequency had no significant effect. The highest days to 50% flowering (45.69) were recorded from the weedy check, and the lowest (41.06) was observed in the weed-free check (Table 4). The reason for delayed or late flowering of mung bean in weedy check was due to the shading of crop plants by weeds that might have reduced sunlight interception thus prolonging the vegetative growth and resulting in delayed days to producing flowers. In line with this result, researchers identified that plants in un-weeded plots took the highest time to reach 50% flowering in common, fava, and mung beans, respectively [24, 23, 12].

Days to 90% physiological maturity

The result of the analysis of variance (ANOVA) revealed that the days to physiological maturity of mung beans were significantly ($p \leq 0.01$) affected by the main effects of weeding frequency. In contrast, the impact of inter-row spacing and its interaction with weeding frequency had no significant effect. Significantly longer days to 90% physiological maturity (79.20) were recorded under weedy check plots. While significantly shorter days to 90% physiological maturity (73.34) were observed in weed-free check (Table 5). The reason for the earlier maturity of mung bean under weed-free treatment was due to exposure of the crop to sunlight that minimizes vegetative growth of the crop and results in early maturity of crops. This result is in harmony with the findings of researcher reported that plants in un-weeded plots took the highest time to reach 90% physiological maturity in common bean, upland rice, and mung bean, respectively [25, 26, 12].

Plant height

The result of analysis of variance (ANOVA) revealed that plant heights of mung beans were significantly ($p \leq 0.01$) affected by the main effects of weeding frequency while inter-row spacing and the interaction of weeding frequency and inter-row spacing had no significant effect. The highest plant height (44.84 cm) was obtained from weedy check treatments than the other, which statistically varied with the remaining weeding frequency (Table 5). The increment of mung bean heights under non-weeded therapies might be due to higher competition of crops with weeds to expose their canopy to sunlight. This result agrees with the report of Tojora & Mekonnen [12], who observed an increase in the plant height of mung bean in the presence of severe weed interference. Nano and Janmejai [23], also reported that the plants in weedy check plots attained significantly higher heights than other weed management practices.

Table 4. *Main effect of inter row spacing and weeding frequencies on phonological and growth parameters of mung bean at Awra district in 2023 main cropping season*

Treatments	**Traits**		
inter-row spacing	**DF**	**DM**	**PH (cm)**
S1	43.15^{a}	76.75^{a}	42.24^{a}
S2	43.06^{a}	76.76^{a}	42.09^{ab}
S3	43.19^{a}	77.05^{a}	42.06^{b}
LSD (0.05)	NS	NS	NS
weed frequency			
W0	45.69^{a}	79.20^{a}	44.84^{a}
W1	43.92^{b}	77.97^{b}	43.24^{b}
W2	41.88^{c}	76.4244^{c}	41.33^{c}
WF	41.06^{d}	73.84^{d}	39.12^{d}
LSD (0.05)	0.32	0.49	0.47
CV (%)	3.67	4.65	5.47

Where: DF= days to flowering, DM= days to maturity, S1=20 cm spacing, S2 =30 cm spacing, S3=40 cm spacing, W0= Weedy check, W1= one-hand weeding at 30 days after sowing, W2= two- hand weeding at 30 and 45 days after sowing, W3=Weed-free check, 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 and NS= non-significant difference.

Yield and Yield Components

Number of pods per plant

The number of pods per plant was significantly ($p \leq 0.01$) affected by the main effects of weeding frequency and plant spacing, while their interaction had no significant effect on the number of pods per plant. The highest number of pods per plant (28.89) was recorded under wider plant spacing of 40 cm than the other treatments, which is statistically at par with 30 cm plant spacing. In contrast, the lowest number of pods per plant (25.88) was recorded under a row spacing of 20cm (Table 5). The possible reason for an increase in the number of pods per plant in wider plant spacing might be due to less competition between plants on resources that causes vigorous growth of plants. This finding is in agreement with the study of Yadav [27], who reported the presence of significant difference due to the main effects of plant spacing; the maximum number of pods per plant was observed at wider plant spacing while a minimum number of pods per plant were observed in narrow spacing. Furthermore, in agreement with the report of Tojora & Mekonnen [12], who reported that higher number of pods per plant was recorded in wider plant spacing than other treatments.

The highest number of pods per plant (34.51) was recorded under a weedy-free check, while the lowest number of pods per plant (19.29) was observed in weed check plots (Table 5). The higher number of pods per plant in weed-free check might be due to the absence of competition for moisture, nutrients, and light from weeds as the plots were kept weed-free throughout the cropping season. In addition, the development of more vigorous leaves might have helped the crop improve the photosynthetic efficiency that may have nourished many pods [28]. This result is in harmony with the findings of researchers, who states that the number of pods produced per plant or maintained up to the final harvest depends on management practices [24, 29, 12].

Number of seeds per pod

The number of seeds per pod was highly significant ($p \leq 0.01$) and affected by the main effects of weeding frequencies and plant spacing. At the same time, their interaction had no significant effect on the number of pods per plant (Table 5.). The results of the present experiment showed that wider row spacing resulted in a higher number of seeds per pod than other treatments. The highest number of seeds per pod (9.72) was achieved by 40cm row spacing, whereas the lowest number of seeds per pod (8.71) was in 20 cm row spacing. The highest number of seeds per pod in wider plant spacing might be due to less competition between plants on resources in broader plant spacing, which caused maximum pod length and resulted in a maximum number of seeds per pod in these plots. This finding agrees with the study of [30, 31], who stated that the widest inter-row spacing (40 cm) gave a significantly higher number of seeds per pod than the other treatment.

Plants kept weed-free throughout the season had the highest (10.44) number of seeds per pod than other treatments. The lowest number of seeds per pod was observed in the weedy check plot. This difference in the number of grains might be due to reduced weed competition, which resulted in more translocation and assimilation of photosynthesis towards grain formation [32]. This finding agrees with the study of Kissi and Reta [29]; Tojora & Mekonnen [12], who reported that the highest number of seeds per pod under weed-free treatment, while the lowest was obtained under weed-infested treatment.

Hundred seed weight (g)

Hundred seed weight was highly significantly ($p \leq 0.01$) affected by the main effects of weeding frequencies. In contrast, the other main effect (plant spacing) and the interaction effect of weeding frequency and plant spacing had no significant effect on the number of pods per plant (Table 5). Plants kept weed-free throughout the season had the highest (6.27) hundred seed weight than other treatments. The highest hundred seed weights (6.27g) were recorded under weed-free plots even if it was statistically at par with the hundred seed weights obtained from plants that were twice weeded (6.13g) and one-time hand weeded (5.97g). The increment of hundred seed weight in weed-free plots might be due to reduced competition between weeds and crops for growth resources, which might have enhanced the availability of nutrients and better translocation of photosynthesis from source to sink and resulted in higher accumulation of photosynthesis in the seeds. Different authors found similar findings [24, 33, 12].

***Table 5**. Effect of inter-row spacing and weeding frequency on yield contributing characters of mung bean at Awra district 2023 main cropping season*

Treatments	**Traits**		
inter-row spacing	**NPP**	**NSPP**	**HSW**
S1	25.88^{b}	8.78^{c}	5.58^{b}
S2	27.89^{a}	9.20^{b}	5.92^{ab}
S3	28.89^{a}	9.72^{a}	5.96 ^{a}
LSD (0.05)	1.01	0.3629	NS
weed frequency	**NPP**	**NSPP**	**HSW**
W0	19.29^{d}	7.98^{d}	4.91^{b}
W1	24.50^{c}	8.89 ^{c}	5.97^{a}
W2	31.9^{b}	9.61^{b}	6.13^{a}
W3	34.51^{a}	10.44^{a}	6.27^{a} 6.13^{a}
LSD (0.05)	1.17	0.42	0.41
CV (%)	4.33	4.64	7.22

Where: NPP= number of pod per plant, NSPP= number of seed per pod, HSW= Hundred seed weight, S1=20 cm spacing, S2 =30 cm spacing, S3=40 cm spacing, W0= Weedy check, W1= one-hand weeding at 30 days after sowing, W2= two- hand weeding at 30 and 45 days after sowing, W3=Weed-free check, 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.

Biomass yield

Aboveground biomass yield was highly significant ($p \leq 0.01$), affected by the main effects of weeding frequencies and plant spacing and by their interaction effect (Table 6). The most significant biomass yield (3736.33 kg ha-1) was obtained as a result of the interaction effect of a wholly weed-free and 30 cm plant spacing pattern, whereas the minimum biomass yield (3340.33 kg ha-1) obtained from the interaction effect of the weedy check under 20 cm inter-row spacing which was statistically at par with the biomass yield obtained in weedy check under 40 cm spacing and one hand weeding under 20 cm spacing (Table 6). This could be due to the combined ability to achieve optimum row spacing and maximum weeding frequency. The result was in line with the findings of Getachew *et al.* [21], who reported that the highest biological yield was attained from the treatment combination of optimum plant spacing and weed-free check. In contrast to this result, Tojora & Mekonnen [12] noted that the interaction effect of weeding frequency and plant spacing had no significant impact on the biomass yield of mung beans.

Seed yield

The result of the analysis of variance revealed that seed yield was highly significantly ($p \leq 0.01$) affected by the main effects of weeding frequencies and plant spacing and the interaction effect of weeding frequency and plant spacing (Table 6). Mean seed yield ranged from 990.33 to 1536.33 kg per ha (Fig. 1 and Table 6). The maximum seed yield (1536.33 kg/ha) was attained from mung beans planted in the interaction of 30 cm inter-row spacing and weed-free check (Fig. 1 and Table 6). This might be due to the combined ability of the absence of weed competition for resources and the effective use of lands in moderate inter-row spacing; this leads to the accumulation of more pods per plant and number of seeds per pod; however, the minimum seed yield was recorded from mung beans planted in the interaction of weedy check and 20 cm row spacing. The result was in line with the findings of Getachew *et al.* [21], who reported that the highest seed yield was attained from the treatment combination of optimum plant spacing and weed-free check in cowpeas. In contrast to this result, Tojora & Mekonnen [12] noted that the interaction effect of weeding frequency and plant spacing had no significant impact on the biomass yield of mung bean.

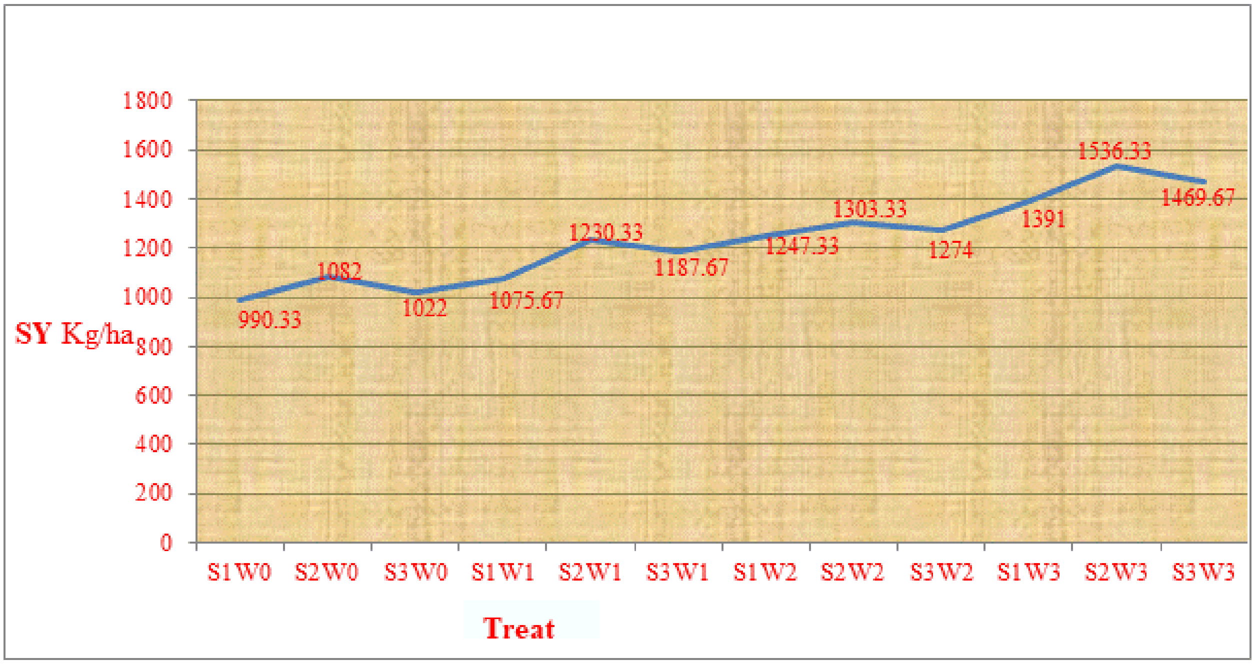

Fig.1. *Effect of different weed frequency and row spacing on seed yield of mung bean at Awra district 2023 main cropping season using a line graph*

S1W0= Weedy check with 20 cm spacing, S2W0= Weedy check with 30 cm spacing, S3W0= Weedy check with 40 cm spacing, S1W1= one-hand weeding at 30 days after sowing with 20 cm spacing, S2W1= one-hand weeding at 30 days after sowing with 30 cm spacing, S3W1= one-hand weeding at 30 days after sowing with 40 cm spacing, S1W2= two- hand weeding at 30 and 45 day after sowing with 20 cm spacing, S2W2= two- hand weeding at 30 and 45 days after sowing with 30 cm spacing, S3W2= two- hand weeding at 30 and 45 days after sowing with 40 cm spacing, S1W3=Weed-free check with20 cm spacing, S2W3=Weed-free check with30 cm spacing, S3W3=Weed-free check with40 cm spacing

Harvesting index

The harvesting index was highly significantly ($P<0.01$) affected by the main effects of inter-row spacing and Weeding frequency, while it was significantly ($P<0.05$) influenced by the interaction effect of weeding frequency and plant spacing (Table 6). The maximum harvest index (41.1) was observed from 30 cm inter-row spacing with a weed-free check. This might be due to intense inter-plant competition for resources such as nutrients, water, and solar radiation at the narrowest spacing. On the other hand, lower yield at the broadest spacing could be due to a sub-optimal population that might not sufficiently exploit the growth resources. A higher harvest index implies higher partitioning of dry matter in grain. On the other hand, the minimum harvesting index (29.64) was found from 20cm inter-row spacing with weedy check, which was statistically similar to 40cm inter-row spacing with weedy check (30.3). This result is in line with Asfaw E [22], who reported that the lowest harvest index (30.52) was observed for the narrowest spacing (30cm) under non-weeded conditions in fava beans. Similarly, Mekonnen *et al.* [26] stated that a higher plant population decreased the harvest index due to drier biomass than grain.

Table 6. *Effect of inter-row spacing and weeding frequency on biomass yield, seed yield, and harvesting index of mung bean at Awra district 2023 main cropping season*

Interaction	BY (kg/ha)	SY (kg/ha)	HI (%)
S1W0	3340.33^{g}	990.33^{h}	29.64^{i}
S2W0	3432.00^{f}	1082.00^{g}	31.53^{h}
S3W0	03372.00^{g}	1022.00^{h}	30.31^{i}
S1W1	3375.67^{g}	1075.67^{g}	31.85^{h}
S2W1	3530.33^{de}	1230.33^{ef}	34.85^{fg}
S3W1	3487.67^{e}	1187.67^{f}	34.05^{g}
S1W2	3497.33^{e}	1247.33^{e}	35.66^{ef}
S2W2	3553.33^{cd}	1303.33^{d}	36.68^{d}
S3W2	3524.0^{de}	1274.00d^{e}	36.15^{de}
S1W3	3591.00^{c}	1391.00^{c}	38.74^{c}
S2W3	3669.67^{a}	1536.33^{a}	41.10^{a}
S3W3	3736.33^{b}	1469.67^{b}	40.05^{b}
LSD	46.88	46.13	0.86
CV	6.79	6.75	5.41

Where: BY= biomass yield, SY= seed yield, HI= harvesting index, S1W0= Weedy check with 20 cm spacing, S2W0= Weedy check with 30 cm spacing, S3W0= Weedy check with 40 cm spacing, S1W1= one-hand weeding at 30 days after sowing with 20 cm spacing, S2W1= one-hand weeding at 30 days after sowing with 30 cm spacing, S3W1= one-hand weeding at 30 day after sowing with 40 cm spacing, S1W2= two- hand weeding at 30 and 45 day after sowing with 20 cm spacing, S2W2= two- hand weeding at 30 and 45 day after sowing with 30 cm spacing, S3W2= two- hand weeding at 30 and 45 days after sowing with 40 cm spacing, S1W3=Weed-free check with20 cm spacing, S2W3=Weed-free check with30 cm spacing, S3W3=Weed-free check with40 cm spacing, 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.

Economic Analysis

Partial budget analysis was done to identify the rewarding treatments. Yield from on-farm experimental plots was adjusted downward by 10% for management difference to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. The total costs for seed, planting, weeding, harvesting, threshing, packing, and transporting vary between the treatments, but all other costs were assumed to be constant throughout the treatments. According to the partial budget analysis, the maximum variable cost was incurred from 20 cm inter-row spacing with a weed-free check. The highest total costs that showed in 20cm inter-row spacing under weed-free was due to the highest cost incurred for most frequently manual weeding to free the plot from weed the whole season. Additionally, its spacing is narrow, so it takes more daily manpower during planting and seed cost as compared to the other treatments (Table 7).

Table 7. *The total variable cost structure of inter-row spacing and weeding frequency of mung bean in Awra*

Input	Quantity	Unit value	Total value	Explanation
20 cm inter-row Seed (kg/ha)	31.25	70	2188	Narrow row spacing took a high quantity of seed
30 cm inter-row Seed (kg/ha)	20.83	70	1458	Moderate row-spacing took an intermediate quantity of seed
40 cm inter-row Seed (kg/ha)	15.63	70	1094	Wider row spacing took low quantity of seed
Labor for planting and weeding (man/ha)	8-27	200	1600-5400	Weed-free check with wide row-spacing treatment took more labor due to the high infestation of weeds in wide row space, while weedy check with wide row spacing took less labor due to wider row spacing taking less labor for sowing compared to narrow row spacing.
Labor for Harvesting and threshing (man/ha)	11-19	200	2200-3400	Weedy check treatment took less labor due to the crops in weedy check are suppressed by weeds, while 30 cm row spacing with weed-free check took more labor due to the presence of moderate plant populations that are free from competition for resource
Labor for packing (man/ku)	2-3	200	400-600	High-yielder treatment took more labor, while less yielder treatment took less labor
Labor for transport (man/ku)	2-3	200	400-600	High-yielder treatment took more labor, while less yielder treatment took less labor

The partial budget analysis revealed that the highest net benefit of birr 82632.70 was obtained from the combined treatment of 30 inter-row space and weed-free check; However, the lowest net benefit of birr 52728.90 was obtained from treatment combinations of 20 cm inter-row spacing with weedy check (Table 8). In contrast to this result, Tojora & Mekonnen [12] noted that the highest net benefit of 34965.2 ETB ha-1 was obtained using 30 cm plant spacing with twice hand weeding. Adula *et al.* [34] Also mentioned was that a 30 cm x 15 cm planting pattern with twice hand hoeing and weeding at two and five WACE had the highest net benefit (42,566 Birr/ha) in fava beans.

Table 8. *Summary cost structure for Inter row spacing and weeding frequency of mung bean in Awra in 2023*

Treatments							
Inter row space	Weeding frequency	For Seed (birr)	Planting, weeding (birr)	Harv & thresh (Eth-birr)	For pack (Eth-birr)	For transport (Eth-birr)	Variable cost (Eth-birr)
20	Weed check	2188	1600	2400	400	400	6988
	One time weeding	2088	2600	3000	400	400	8488
	Two-time weeding	2188	3600	3450	450	450	10138
	Weed free check	2188	4000	3600	500	500	10788
30	Weed check	1458	1500	2400	400	400	7558
	One time weeding	1458	2500	3400	450	450	8258
	Two-time weeding	1458	3200	3400	480	480	9018
	Weed free check	1458	3750	3600	600	600	10008
40	Weed check	1094	1200	2400	400	400	5494
	One time weeding	1094	3600	2500	430	430	8054
	Two-time weeding	1094	4000	2400	470	470	8434
	Weed free check	1094	5400	2200	600	600	9894

Dominance Analysis

The mung bean seeds from different treatments are sold at various costs due to the difference in quality. That is, the seed attained from the weedy check treatment with all row spacing sold at a lower price; however, seeds attained from weed-free check with all row spacing sold at a better price. Dominance analysis is critical because it empowers decision-makers with a structured understanding of variable importance, which leads to more strategic, evidence-based, and resource-efficient decisions. So the dominance analysis of the present experiment showed that all treatment combinations except 20 cm inter-row spacing combined with a weedy check, one-time weeding, and two times weeding, and also 40 cm combined with weedy check were un-dominated treatments as their net benefits were greater than those of treatments with lower variable costs. Hence, all dominated treatments were eliminated from further consideration for the marginal rate of return analysis.

All undominated treatments gave a marginal rate of return (MRR) greater than the minimum acceptable rate of return (100%). The highest MRR (%) was obtained from 30 cm inter-row spacing and weed-free check, followed by 30 cm inter-row spacing with two times weeding frequency. The combination of 30 cm inter-row spacing with weed-free check gave the highest percent of MRR (%) 3426 with a net benefit of (82632.70 ETB ha^{-1}) followed by the combination of 30cm inter-row spacing with two times weeding which gave a percent of MRR 2465.52 with a net benefit of (69572.80 ETB ha^{-1}), and the combination of 40 cm inter-row spacing with two times weeding and weed-free check respectively. The result agreed with that of [22], who found a higher profit for fava beans from wider inter-row spacing and two times the weeding frequency in fava beans.

Table 9. *Economic analysis for Inter row spacing and weeding frequency on mung bean seed yield in Awra in 2023*

Treatments								
Inter row space	Weeding frequency	AvY (kg/ha)	AjY (kg/ha)	GFB (Eth-birr)	TVC (Eth-birr)	NB (Eth-birr)	MRR	(%)
40	Weed check	1022	919.8	58407.3	5494	52913.3		D
20	Weed check	990.33	891.297	59716.9	6988	52728.9	-0.12	D
30	Weed check	1082	973.8	57609.76	7558	57571.056	8.50	849.50
40	One time weeding	1187.67	1068.903	66806.44	8054	58752.438	2.38	238.18
30	One time weeding	1230.33	1107.297	69206.06	8258	60948.063	10.76	1076.29
40	Two-time weeding	1274	1146.6	73382.4	8434	64948.4	22.73	2272.92
20	One time weeding	1075.67	968.103	61474.54	8488	52986.541	-221.52	D
30	Two-time weeding	1303.33	1172.997	75071.81	9018	69572.8	24.66	2465.52
40	Weed free check	1469.67	1322.703	88621.1	9894	68727.102	14.47	1446.72
30	Weed free check	1536.33	1382.697	92640.7	10008	82632.7	34.26	3426
	Two-time weeding	1247.33	1122.597	71846.21	10138	61708.208	-160.96	D
20	Weed free check	1391	1251.9	83877.3	10788	63089.301	17.51	1750.94

Where: AvY-average yield; AjY- adjustable yield; TVC-total variable cost; GFB-growth field benefit; NB-net benefit

CONCLUSION

Mung bean (*Vigna radiata* L.) is an important pulse crop in the Fabaceae family. However, its productivity is low mainly due to a lack of optimum plant population and inappropriate weed management practices. Thus, the present experiment was conducted using three inter-row spacing and four weeding frequencies, laid out in an RCBD factorial arrangement with three replications, to evaluate the effects of weeding frequency and inter-row spacing on the growth, yield, and yield components of mung bean (*Vignaradiata*).

The results of ANOVA revealed that weed density, weed dry weight, weed control efficiency, weed yield, biomass yield, and harvesting index were significantly ($P<0.05$) affected by the interaction effect of inter-row spacing and weeding frequency. The highest seed yield (1536.33kg ha^{-1}) and the highest percent of MRR (3426) with the highest net benefit (82632.70 ETB ha^{-1}) was obtained from the interaction of 30 cm inter-row spacing and weed-free check followed by the combination of 30cm and 40 cm inter-row spacing with two times weeding respectively. So it can be concluded that the use of 30 cm inter-row spacing with the weed-free check was the best both agronomically efficient and economically viable and is recommended as the first option for mung bean production, followed by the combination of 30 cm and 40 cm inter-row spacing with two times weeding frequency as second and third options respectively. However, as this study was conducted for one season and at one location, further study needs to be done over seasons and locations to determine optimum plant populations and weed management options for better recommendations.

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