Effect of inter- and intra-row spacing on yield and yield components of mung bean (*Vigna radiata* L.) under rain-fed condition at Metema District, northwestern Ethiopia

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Abstract

Background: The study was conducted in 2017 main cropping season at two locations in North Gondar Zone, Ethiopia, to determine the optimum inter- and intra-row spacing of mung bean for maximum yield and yield components. The experiment was laid in a randomized complete block design with three replications in a factorial arrangement of four inter-row (20, 30, 40 and 50 cm) and three intra-row (5, 10 and 15 cm) spacing using mung bean variety Rasa (N-26).

Results: Significant interaction effect of inter- and intra-row spacing was observed for days to maturity, number of branches per plant, number of pods per plant, grain yield, harvest index, days to flowering, plant height and above-ground dry biomass yield. The highest grain yield (1882.67 kg ha^{-1}) was obtained at interaction of 40 × 10 cm spacing, while the lowest (1367.8 kg ha^{-1}) was obtained from 20 × 5 cm spacing. However, the result of economic analysis showed that the maximum net benefit was obtained at spacing of 40 × 15 cm.

Conclusions: Based on agronomic performance and economic analysis, use of 40 × 15 cm is promising for mung bean production in Metema District and similar agroecologies.

Keywords: Economic analysis, Intra-row spacing, Plant spacing, Mung bean, Row spacing

Background

Mung bean (*Vigna radiata* L.) is one of the most important pulse crops, grown from tropical to subtropical areas around the world [1]. It is an important wide-spreading, herbaceous and annual legume pulse crop cultivated mostly by traditional farmers [2]. At present, mung bean cultivation spreads widely in Africa, South America, Australia and in many Asian countries [3]. The world annual production area of mung bean is about 5.5 million hectare with a increase in rate of 2.5% per annum [4]. Its requirement in growing in areas where the rainy season is short, and its wide adaptability together with

its digestibility makes mung bean cultivated all over the world [3]. Mung bean is utilized in several ways; seeds, sprouts and young pods are all consumed and provide a rich source of amino acids, vitamins and minerals [5]. The grain contains 24.2% protein, 1.3% fat and 60.4% carbohydrate [6]. It has low calories and is rich in fiber and easily digestible crop without causing flatulence as happens with many other legumes [7]. The crop is characterized by fast growth under warm conditions, low water requirement and excellent soil fertility enhancement via nitrogen fixation [8]. Currently, mung bean is produced in different parts of Ethiopia. It is mainly cultivated in North Shewa, Harerge, Illubabor, Gamo Gofa, Tigray and Gondar. Farmers in some moisture stress areas of Ethiopia effectively use and produce it to supplement their protein needs [9]. Ethiopia's green mung bean export has grown slightly from 822 tons in (2001) to 26,743 tons in

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2014 to fulfill the demand of India, Indonesia, Belgium and the UAE [10, 11]. In Ethiopia, mung bean covers about 27,086 ha of land and produces 241,589.90 tons in main cropping season per annum with average productivity of 0.9 ton ha^{-1} [12].

Even though there are high potential uses and export demand, the productivity of mung bean is low in Ethiopia (0.9 ton ha^{-1}) as compared to the world average productivity of 1.2 ton ha^{-1}, which is due to abiotic and biotic factors such as lack of improved variety, disease, insect and agronomic practices like in optimum row spacing and plant population per unit area. Proper method of sowing is among the important biotic factors that determine the proper plant population, which improves the performance and productivity of plants in the field. Plant population plays an important role as it is one of the most important yield contributing characters [13]. Combinations of researches on inter- and intra-row spacing is lacking in boosting productivity of mung bean in northwestern Ethiopia. Therefore, the present study was conducted to investigate the optimum inter- and intra-row spacing of mung bean for maximum yield and yield components and to evaluate the economic feasibility of different inter- and intra-row spacing of mung bean.

Materials and methods

The field experiment was conducted at Kumer and Kokit areas of Metema District from July to September 2017 in the main cropping season. Metema District is located in North Gondar Zone of Amhara Regional State, Ethiopia. Metema has latitude, longitude and elevation of 12°47′′38′N, 36°23′′41′E and 760 m above sea level, respectively. It has average annual rainfall of 1030 mm. It has maximum and minimum temperatures of 40.0 and 15.0 °C, respectively [14]. The soil type is sandy loam and reddish brown color. The mung bean variety *Rasa* (N-26) was used for the experiment.

Factorial combinations of four inter-rows (20, 30, 40 and 50 cm) and three intra-rows (5, 10 and 15 cm) spacing were laid out in a randomized complete block design with three replications. Each experimental plot had 2.5 and 4 m length and width, respectively. Spacing between plots and replications were 1 and 1.5 m, respectively. Planting was done when there was adequate soil moisture in the field. DAP fertilizer was applied at a rate of 100 kg ha^{-1}, and all other management practices were performed as per the general recommendations for green bean [15].

Data were collected on major agronomic and phenological characters. Analysis of variance (ANOVA) was done using SAS software [16]. Homogeneity of variances was tested using *F* test as described by Gomez and Gomez [17]. According to the homogeneity test, all parameters were homogenous except the number of branches per plant and number of pods per plant. As a result of it, the two parameters were analyzed in separate locations. Least significant differences (LSD) test at 5% level of probability was used. The partial budget analysis as described by CIMMYT [18] was done to determine the economic feasibility. The net benefit was calculated as the difference between the gross field benefit (Ethiopian Birr ha^{-1}) and the total costs (Ethiopian Birr ha^{-1}) that varied.

Results and discussion

Days to flowering

The combined main effect of inter- and intra-row spacing was highly significant ($P < 0.01$), while their interaction had no significant effect on days to 50% flowering (Table 1). The longest days to 50% flowering (40.83 cm) were recorded at inter-row spacing of 50 cm, while the shortest days to 50% flowering (36.05) were recorded at 20 cm inter-row spacing (Table 2). The longest days to 50% flowering (39.86) were recorded at wider (15 cm)

Table 1 The combined mean square values of ANOVA for phenology, growth and yield components of mung bean inter- and intra-rows spacing at Metema, 2017

SOV	DoF	DF	DM	PH	PL	SPP	DBY (kg ha^{-1})	AGY (kg ha^{-1})	TSW	HI
REP	2	9.39*	0.79^{ns}	219.50**	0.28^{ns}	0.41^{ns}	108,938.01^{ns}	20,723.51*	0.18^{ns}	0.01^{ns}
PS	2	27.18**	10.13**	337.89**	0.074^{ns}	0.32^{ns}	3,140,693.43**	158,340.93**	7.15^{ns}	0.10**
RS	3	91.13**	40.53**	191.65**	0.40^{ns}	0.36^{ns}	11,827,511.24**	175,899.87**	29.47^{ns}	0.22**
Site	1	66.13**	21.13**	302.99**	0.25^{ns}	0.002^{ns}	375,700.01*	747.56^{ns}	1.75**	0.01*
RS*PS	6	0.79^{ns}	4.31**	44.82^{ns}	0.36^{ns}	0.27^{ns}	20,817.43^{ns}	62,836.63**	1.58^{ns}	0.01*
Error	52	2.14	1.08	23.52	0.52	0.38	59,438.14	5636.839	3.71	0.002

NS nonsignificant, *SOV* source of variation, *CV* coefficient of variation, *Rep* replication, *PS* plant spacing, *RS* row spacing, *DF* days to flowering, *DM* days to maturity, *PH* plant height, *PL* pod length, *SPP* seed per pod, *DBY* dry biomass yield, *AGY* adjusted grain yield, *TSW* thousand seed pod, *HI* harvest index, *LSD* least significant difference at 5%

*Significant difference at $P < 0.05$; **highly significant differences at $P < 0.01$

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Table 2 The combined main effects of inter- and intra-row spacing on days to 50% flowering and plant height, and aboveground dry biomass yield mung bean at Metema, 2017

	Days to flowering	Plant height	Dry biomass yield (kg ha^{-1})
Intra-rows (PS)			
5	37.75c	80.43a	4009.92a
10	38.92b	76.63b	3548.21b
15	39.86a	72.92c	3296.67c
LSD (5%)	0.85	2.81	141.23
Inter-rows (RS)			
20	36.05c	79.83a	4503.11a
30	38b	77.16a	3962.39b
40	40.5a	77.5a	3400.44c
50	40.83a	72.09b	2607.11d
LSD (5%)	0.98	3.25	163.07
CV (%)	3.76	6.33	6.74

Means in the same column and the same letters are not significantly different at 5% level of probability

NS nonsignificant, *LSD* least significant difference at 5% level of significant, *CV* coefficient of variation in percent

Table 3 The combined interaction effect of inter- and inter-row spacing on days to 90% maturity of mung bean at Metema, 2017

Inter-rows (RS)	Intra-rows (PS)		
	5	10	15
20	61.17e	61.17e	60.6e
30	60.5e	62.5dc	61.17e
40	61.5de	63.17bc	64.17ba
50	63.33bc	64.17ba	65.17a
LSD (5%)	1.28	CV (%)	1.8

Means in the same column and the same letters are not significantly different at 5% level of probability

NS nonsignificant, *LSD* least significant difference at 5% level of significant, *CV* coefficient of variation in percent

intra-row spacing, while the shortest (37.75) were recorded at narrow (5 cm) intra-row spacing (Table 2). The longest days to flowering with a wider inter- and intra-row spacing might be due to the fact that more nutritional area available in the wider row spacing might have caused the crop to flower later than the narrower spacing. Furthermore, this result might be because wider spacing had a better light interception as compared to the narrow row spacing, resulting in more number of days to flowering of mung bean. This result is in line with Samih [19] who reported that when beans are planted at the lower planting densities, the plants required more number of days for flowering.

Days to 90% maturity

The combined main effect of inter- and intra-row spacing and their interaction was highly significant ($P < 0.01$) on days to 90% maturity (Table 1). The longest days to 90% maturity (65.17) were recorded at interaction of 50 cm inter- and 15 cm intra-row spacing, while the shortest days to 90% maturity (60.5 cm) was recorded at 20 cm inter- and 5 cm intra-row spacing (Table 3). The prolonged days to 90% maturity with the lowest population density or wider inter-row and intra-row spacing might be due to less competition of light interception, high availability of growth resources that promote luxurious growth enhanced the lateral growth and prolonged maturity. This result was not in line with that of Oad et al. [20]

who stated that the interaction of wider inter- and intra-row spacing hastened maturity of safflower.

Plant height (cm)

The combined main effect of inter- and intra-row spacing was highly significant ($P < 0.01$), while their interaction had no significant effect on plant height (Table 1). The maximum plant height (79.83 cm) was recorded at inter-row spacing of 20, 30 and 40 cm (Table 2).

With regard to the effects of intra-row spacing, the maximum plant height (80.43 cm) was recorded at narrow intra-row spacing of 5 cm (Table 2). The present result is in line with Shamsi and Kobraee [21] who found taller plants were recorded at narrow spacing, while the shortest plants at wider spacing on mung bean.

Number of branches per plant

Results from the analysis of variance showed that both the main effect and their interaction effect of inter- and intra-row spacing were highly significant ($P < 0.01$) on the number of branches per plant at Metema site two (Table 4), whereas, at site one, the main effect was significant ($P < 0.01$), while their interaction had no significant effect on the number of branches per plant (Table 4). The highest number of branches per plant (10.4) was obtained from 50×15 cm inter- and intra-row spacing followed by 9.67 at 40×15 cm (Table 5), while the lowest number of branches per plant (3.13) was found at 20×5 cm at Metema site two (Table 5). This result was in line with El Naim et al. [22] who reported that the number of branches per plant was reduced with the increase in plant density. Moreover, our finding is in line with Mehmet [23] who stated that as spacing gets wider, there will be more interception of sunlight for photosynthesis, which results in the production of more nutrients for partitioning toward the development of more branches.

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Table 4 Mean square values of ANOVA for the number of branches per plant and pods per plant of mung bean as affected by inter- and intra-row spacing at Metema, Locations one and two, 2017

SOV	DF	Location one		Location two	
		NBPP	NPPP	NBPP	NPPP
REP	2	5.04*	22.58^{ns}	2.42*	4.12^{ns}
PS	2	25.88**	206.92**	53.83**	332.01**
RS	3	16.08**	196.11**	19.76**	131.13**
RS*PS	6	0.63^{ns}	5.50^{ns}	3.55**	17.13**
Error	22	1.18	11.57	0.45	2.89

NS nonsignificant at $P < 0.05$, *Rep* replication, *PS* plant spacing, *RS* row spacing, *SOV* source of variation, *DoF* degree of freedom, *NBPP* number of branches per plant, *NPPP* number of pods per plant

*Significant at $P < 0.05$; **highly significant differences at $P < 0.01$

Table 5 Interaction effect of inter- and intra-row spacing on number of branches per plant of mung bean at Metema Location two, 2017

Inter-rows (RS)	Intra-rows (PS)			Mean
	5	10	15	
20	3.13e	4.33dc	5.27c	4.24
30	3.87dc	4.8dc	6.6b	5.09
40	3.87de	7.53b	9.67a	7.02
50	4.13de	7.33b	10.4a	7.29
Mean	3.75	6	7.98	
LSD (5%)	1.13	CV (%)	11.29	

Means in the same column and the same letters are not significantly different at 5% level of probability

NS nonsignificant, *LSD* least significant difference at 5% level of significant, *CV* coefficient of variation in percent, *PS* plant spacing, *RS* row spacing

Number of pods per plant

Results from the analysis of variance indicated that both the main effect and their interaction effect of inter- and intra- row spacing were highly significant ($P < 0.01$) on the number of pods per plant (Table 4) at Metema site two. Similarly, the main effect of inter- and intra-row spacing at site two was significant ($P < 0.01$), while their interaction had no significant effect on the number of pods per plant (Table 4). 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 at Metema site two (Table 6). This result was in line with Malek et al. [24] who reported that the number of pods per plant of lentil was significantly influenced by plant density.

Pod length (cm), number of seeds per pod and thousand seed weight (gm)

In the current study, the combined analysis showed that both main effect and their interactions effect of inter- and intra-row spacing were not significant ($P < 0.05$) on pod length, number of seeds per pod and thousand seed weight (Table 1). This result was in line with Ihsanullah et al. [25] who stated that no significant effect of different row spacing and plant densities on pod length of mung bean. This result was in line with the finding of Ihsanullah et al. [25] who reported no significant effect of row spacing on number of seeds per pod of mung bean. The present result was in line with Lemlem [26] who obtained no significant effect of plant density on hundred seeds weight of soya bean.

Aboveground dry biomass yield (kg ha^{-1})

The combined main effect of inter- and intra-row spacing was highly significant ($P < 0.01$), while their interaction had no significant effect on aboveground dry biomass yield (Table 1). The highest aboveground dry biomass yield (4503.11 kg ha^{-1}) was recorded at 20 cm inter-row spacing which was significantly decreased by wider spacing of 30, 40, and 50 cm spacing, while the lowest value for dry biomass yield (2607.11 kg ha^{-1}) was obtained at 50 cm inter-row spacing (Table 2). Regarding the effect of intra-row spacing, the aboveground dry biomass increased with a decrease in intra-row spacing where the highest aboveground dry biomass yield (4009.92 kg ha^{-1}) was recorded at narrow intra-row spacing of 5 cm, which had a significant difference with 10 cm, while the lowest aboveground dry biomass yield (3296.67 kg ha^{-1}) was recorded at wider intra-row spacing of 15 cm (Table 8). This result was in agreement with Solomon [27] who reported that dry biomass per hectare was significantly increased with increased plant density on haricot bean.

Adjusted grain yield (kg ha^{-1})

The combined analysis showed main effect and their interaction effect of inter- and intra-row spacing which were highly significantly ($P < 0.01$) affected on grain yield of mung bean (Table 1). 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 1367.83 and 1401.5 kg ha^{-1} were obtained at interaction of 20×5 cm and 50×15 cm inter- and intra-row spacing, respectively (Table 7).

At very higher population (20×5 cm), the adverse effect on the yield was noticed which might be due to intense interplant competition and floral abortion.

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Table 6 Interaction effect of intra- and inter-row spacing on number of pods per plant of mung bean crop at Metema location two, 2017

Inter-rows	Intra-rows		
	5	10	15
20	7.53e	11.33dc	13c
30	9.53de	13.13c	19b
40	9.73de	19.87b	21.53b
50	11.73dc	19.73b	26.73a
LSD (5%)	2.88		
CV (%)	11.16		

Means in the same column and the same letters are not significantly different at 5% level of probability

NS nonsignificant, *LSD* least significant difference at 5% level of significant, *CV* coefficient of variation in percent, *PS* plant spacing, *RS* row spacing

Table 7 The combined interaction effect of intra- and inter-row spacing on adjusted grain yield (kg ha^{-1}) of mung bean at Metema, 2017

Inter-rows (RS)	Intra-rows (PS)		
	5	10	15
20	1367.83f	1492.67ed	1609.33cb
30	1429.17ef	1551.33cd	1597.17cb
40	1536.17cd	1882.67a	1652.17b
50	1491.83ed	1533.83cd	1401.5f
LSD (5%)	87.731		
CV (%)	4.88		

Means in the same column and the same letters are not significantly different at 5% level of probability

NS nonsignificant, *LSD* least significant difference at 5% level of significant, *CV* coefficient of variation in percent, *PS* plant spacing, *RS* row spacing

Table 8 The combined interaction effect of intra- and inter-row spacing on harvest index of mung bean at Metema, 2017

Inter-rows (RS)	Intra-rows (PS)		
	5	10	15
20	0.28g	0.38fg	0.39fe
30	0.33g	0.40e	0.44de
40	0.41e	0.58ab	0.54bc
50	0.49cd	0.62a	0.62a
LSD (5%)	0.06	CV (%)	10.57

Means in the same column and the same letters are not significantly different at 5% level of probability

NS nonsignificant, *LSD* least significant difference at 5% level of significant, *CV* coefficient of variation in percent

Besides, at spacing of 20 cm × 5 cm, the grain yield ha^{-1} was significantly higher as compared to the interaction of wider inter- and intra-row spacing (50 × 15 cm), which showed that the main determinant of yield was the plant population which along with other yield attributes contributed toward a significant increase in grain yield (Table 7). This result was in line with Abuzar et al. [28] who observed that the lowest grain yield was recorded at the highest population. In Bangladesh, as well as in other countries, various experiments with improper spacing reduced the yield of mung bean up to 20–40% [29].

Harvest index
The combined main effect of intra- and inter-row spacing had a significant ($P < 0.01$) effect on harvest index (Table 1). Moreover, the interaction effect of intra- and inter-row spacing effect on harvest index was significant ($P < 0.05$) (Table 1). The highest harvest index (62%) was obtained at interaction of (50 × 10) cm followed by (50 × 15) cm spacing, while the lowest (28% and 33%) harvest index was obtained at interaction of (20 × 5) and (30 × 5) cm, respectively (Table 8). Similar result was reported by Khan et al. [30] who recorded maximum harvest index (41.66%) at the highest row spacing (45 cm) of chickpea than 15 cm row spacing (32.6%).

Economic analysis
Results of the economic analysis of the present experiment showed that the maximum net benefit of Ethiopian birr (ETB) 22,185.7 ha^{-1} with an acceptable marginal rate of return (MRR) (>100%) was obtained from planting of mung bean with 40 × 15 cm spacing (Table 9). Farmers may have the opportunity to decrease seed and labor cost and to increase mung bean yield and ultimately improve their livelihoods through adopting the appropriate management practices. The present finding demonstrated that optimum economic plant densities of mung bean are often less than densities that result in maximum yield, because of higher labor and seed costs at higher densities. This result is in line with [31] who reported that changes in seeding rates contributed to significant yield changes but not to changes in profitability.

Conclusions
Generating reliable information on agronomic management practices such as appropriate row and plant spacing is quite important to come up with profitable and sustainable mung bean production and productivity. In view of this, an experiment was conducted to determine the effect of intra- and inter-row spacing on the yield and yield components of mung bean.

Table 9 Economic analysis for inter- and intra-row spacing of mung bean at Metema, 2017

	Average yield (kg ha^{-1})	Adjusted yield 10% (kg ha^{-1})	GB (ETB/ha)	TVC (ETB/ha)		DA	
50X15	1367.83	1231.05	22,158.85	3599.305	19,105	–	
40X15	1492.67	1343.40	24,181.25	4579.456	22,185.7	–	314.308
50X10	1609.33	1448.40	26,071.15	5621.72	19,226.33	D	
30X15	1429.17	1286.25	23,152.55	5956.173	19,917.98	D	
40X10	1551.33	1396.20	25,131.55	7144.15	23,355.1	–	45.596
20X15	1597.17	1437.45	25,874.15	9155.312	16,915.83	D	
30X10	1536.17	1382.55	24,885.95	9294.595	15,836.95	D	
50X5	1882.67	1694.40	30,499.25	11,243.44	12,924.21	D	
20X10	1652.17	1486.95	26,765.15	14,288.3	9892.954	D	
40X5	1491.83	1342.65	24,167.65	14,288.3	10,597.65	D	
30X5	1533.83	1380.45	24,848.05	18,587.39	4565.164	D	
20X5	1401.5	1261.35	22,704.30	28,576.6	− 6417.75	D	

GB gross benefit, *ETB* Ethiopian birr, *TVC* total variable cost, *NB* net benefit, *DA* dominance analysis, *MRR* marginal rate of return

This study provides evidence that inter- and intra-row spacing has influence on the phenology, growth, yield and yield components of mung bean. However, for maximum net benefit, we recommend spacing of 40×15 cm as the optimum spacing for the cultivation of mung bean variety Rasa (N-26) under the rain-fed in North Gondar Zone, Metema Districts, and similar agroecologies.

Abbreviations
ANOVA: analysis of variance; ETB: Ethiopian birr; MRR: marginal rate of return.

Authors' contributions
AB initiated the research, wrote the research proposal, conducted the research, did data entry and analysis and wrote the manuscript. TT and DT were involved in analysis, methodology, writing, reviewing and editing of research proposal and manuscript. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
The authors want to declare that they can submit the data at whatever time based on your request. The datasets used and/or analyzed during the current study will be available from the corresponding author on reasonable request.

Consent for publication
Not applicable.

Ethics approval and consent to participate
Not applicable since the study involved mung bean plants.

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