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Effect of intra row spacing and NPS fertilizer rate on yield and yield components of mung bean (*Vigna radiata* L.) in ARBA Minch district, Southern Ethiopia

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Abstract
Mung bean is becoming an important pulse crop in dry land areas of Ethiopia. However, its productivity is influenced by intra row spacing and nutrient management in a given environment. Accordingly, a field experiment was conducted to determine the optimum level of intra row spacing and NPS fertilizer rate for enhanced productivity of mung bean in the ARBA Minch district. It was carried out during the 2021 cropping season, and the treatments consisted of factorial combinations of four intra row spacing (5, 10, 15 and 20 cm) with five NPS fertilizer rates (0, 50, 100, 150 and 200 kg ha^{-1}) laid out in RCBD with three replications. Results revealed that the interaction of intra row spacing and NPS fertilizer rate was significant (p<0.05) for the number of days to maturity, plant height, number of pods per plant, dry biomass yield, and grain yield. However, it was insignificant (p>0.05) in terms of the number of days to flowering, nodulation parameters, number of primary branches per plant, number of seeds per pod, and hundred seed weight. It was observed that the NPS fertilizer rate highly significantly affected the number of days to 50% flowering, the number of primary branches per plant, and nodule parameters, the highest values of which were recorded for application of 200 kg ha^{-1}, whereas the highest number of seeds per pod, and hundred seed weight were recorded for 100 kg of NPS ha^{-1}. The result also showed that an intra-row spacing of 20 cm showed significantly higher values for the number of days, 50% flowering, number of primary branches per plant, number of seeds per pod, and hundred seed weight. The interaction effect resulted in the highest number of days to 90% physiological maturity for recorded 20 cm with 200 NPS $kgha^{-1}$ while showed maximum values of plant height, leaf area index and above ground dry biomass yield for recorded 5 cm with NPS 200 $kgha^{-1}$. On the other hand, significantly higher values of the number of pods per plant, seed yield, harvest index and net return with acceptable MRR were recorded for intra row spacing of 10 cm with 100 kg of NPS ha^{-1}. Therefore, it was concluded that the application of 100 kg NPS fertilizer ha^{-1} with 10 cm intra row spacing could enable producers to harvest better mung bean yield and get more economic return from the crop in the study area.

Keywords: Blended fertilizer, fertilizer, grain yield, intra row pacing, Mung bean

Introduction
Mung bean (*Vigna radiata* L.) is among the important pulses cultivated in different agro ecological zones of the world (Khan *et al*. 2012) [19]. It is a warm-season annual crop characterized by fast growth under warm conditions, low water requirement, and excellent soil fertility enhancement through biological nitrogen fixation (Das *et al*. 2014; Yagoob and Yagoob, 2014) [5, 32].

Mung bean is locally called "Masho" in Amharic. It is an important pulse crop for smallholders that has recently gained attention and was announced as the sixth export commodity by the Ethiopian Commodity Exchange (ECX 2014). According to CSA (2018) [4], mung bean is produced at about 41 633.2 ha with a total production of 514 227.41 t and an average productivity of 1.23 t ha^{-1} in Ethiopia.

Different authors reported low productivity of mung bean in Ethiopia compared to the production reported in other countries, which might be attributed to the cultivation of mung bean in marginal lands without sufficient fertilizer, methods of cultivation, poor crop stand, limited fertilizer application, poor plant protection measures, and lack of high yielding varieties were found to be the main reasons for low productivity. Nutrient management of mung bean affects crop growth, development and the final product.

According to Achakzai *et al*. (2012) [33], reported by Sisay and Zenebe (2021) [34], mung beans, like other legumes, require nitrogen, phosphorus, potassium, and sulfur for growth and development.

The management of fertilizer is one crucial factor that significantly affects the growth and yield of the mung bean. Moreover, the intra-row spacing of plants depends on the availability of environmental resources for which plants compete and the growth patterns and morphological characteristics of the competing plants. In line with this, it has been reported that optimum intra row spacing of the plant can significantly improve mung bean yield (Kabir and Sarkar 2008; Singh *et al*. 2012) [16, 27]. Thus, this study was initiated to determine the optimum intra-row spacing and NPS rate for improved productivity of mung bean in ARBA Minch district of Southern Ethiopia.

Methodology

Description of the Study Area

The study was conducted in ARBA Minch district, Southern Ethiopia. It is geographically situated at 6°03'00" N latitude and 37°36'00" E longitude and an altitude of 1278 M.A.S.L. The district's average minimum and maximum temperatures are 17.30 °C and -30.60 °C, respectively. The rainfall pattern of the study district is characterized by a bimodal distribution in Belg and Meher seasons with an average total annual amount of 830.7 mm. The main crops grown mainly in the study district are teff, maize, and legumes, especially mung bean and haricot bean, and fruit trees, especially banana, mango, papaya, and avocado.

Experimental design and treatments

The experiment was laid out in randomized complete block design (RCBD) with three replications. The treatments consisted of 20 factorial combinations of four intra row spacing of mung bean plants (5, 10, 15 and 20 cm) and five levels of NPS fertilizer (0, 50, 100, 150 and 200 $kgha^{-1}$). The inter-row spacing was set at 40 cm in all the plots, which corresponded to the plant density of 500000, 250000, 166000 and 125000 plants ha^{-1}. The total area of the field was 480 m^2, with a net experimental area of 288 m^2. The spacing between blocks and plots was 1.00 m and 0.50 m, respectively.

Experimental Procedures and Agronomic Managements

The experimental field was prepared from February to March 2021 with oxen and then harrowed twice by human labour. All unwanted materials and plant residues were removed. The land was divided into three blocks, each with twenty plots. Treatments were randomly assigned to each plot. Fertilizer was hand drilled in rows of the respective plots. Two seeds per hill were sown and thinned to one plant per hill after establishment. All other field management practices were uniformly applied to all plots based on the recommendation for mung bean (EARO, 2016) [8].

Soil Sampling Collection and Analysis

Soil samples were collected from 0-20 cm depth in a zigzag pattern using an auger at an interval of eight meters before the experimental field was ploughed. The samples from each spot were mixed thoroughly and quartered to obtain one representative composite sample. The composited samples of 1 kg were labelled correctly and then taken to the chemistry laboratory of ARBA Minch University.

Soil samples were analyzed for total nitrogen using the Kjeldahl digestion, distillation, and titration method as described by Black (1934) [31]. Soil pH was measured potentiometrically in 1:2.5 soil-water suspensions with a standard glass electrode pH meter (Van Reeuuwijik 1992) [30]. Available Phosphorus was determined using the Olsen extraction method as described by Olsen *et al*. (1954) [25]. Available sulfur was analysed by turbid metric method. Cation Exchange Capacity (CEC) was determined by the ammonium acetate method. Electro-conductivity was determined by a standard glass electrode using EC meter. The volumetric method determined Organic carbon content (Walkey and Black 1934) [31]. Exchangeable bases such as Ca, Mg, K and Na were determined after extracting the soil samples with ammonium acetate (1N NH_4OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts were analysed using an atomic absorption spectrophotometer, while Na and K were analyzed by flame photometer.

Crop data collection and Analysis

Data on phonological attributes, such as days to 50% flowering and days to 90% physiological maturity were collected. Growth attributes such as leaf area, leaf area index, plant height and number of branches per plant were determined from five randomly selected plants. The total number of nodules per plant was determined by counting the number of nodules produced by five randomly selected plants from destructive rows of each plot. Cutting each nodule with a sharp blade determined the number of effective nodules per plant. Yield and yield components such as number of pods per plant, number of seeds per pod and total above ground dry biomass yield were determined from five plants harvested from the central rows of each plot. Hundred seed weight was determined by the weight of a hundred randomly sampled seeds after threshing and adjusting to 10% moisture content. Grain yield was measured by harvesting and threshing five randomly selected plants from the central rows of each plot. Harvest Index was recorded as the ratio of grain yield to total above ground biomass yield and multiplied by one hundred.

Statistical analysis

Data collected for various growth, yield, and yield related parameters were subjected to Analysis of Variance (ANOVA) using statistical analysis software (SAS, version 9.0). Interpretations were made following the procedure described by Gomez and Gomez (1984) [14], and mean separation was carried out using the least significant difference (LSD) test at 5% P level. A simple correlation analysis was done using SAS, version 9.0, to determine the relationship between plant parameters affected by intra-row spacing and NPS fertilizer.

Partial budget analysis

The partial budget analysis was carried out using the methodology described by CIMMYT (1988) [3]. To determine yield and profit maximization rate of seed and fertilizer, the marginal revenue and marginal cost analysis was used. The total variable cost was calculated as the sum of costs incurred for NPS fertilizer, seed and labor. On the other hand, market price of grain during harvesting time was taken as value for determination of revenue.

Results

Soil Physicochemical Properties

Results of the laboratory analysis revealed that soil texture of the experimental site is clay loam (USDA 1987) [29] with a pH value of 7.9 (Table 1), which is moderately alkaline (Tekalign 1991) [28]. In line with this, it has been reported that mung bean grows on a wide range of soils with pH ranging from 5-8, and it is somewhat tolerant to saline soils (Mogotsi 2006) [23].

Table 1: Selected soil properties before planting

Soil characters	Values	Rating	Reference
Soil Texture			
Clay (%)	65		
Silt (%)	27		
Sand (%)	14		
Textural class	Clay loam	Medium texture	USDA (1987) [29]
Soil pH	7.91	Moderately alkaline	Tekalign *et al*. (1991) [28]
Electro-conductivity (ds/m)	1.94	Medium	Tekalign *et al*. (1991) [28]
Organic carbon (%)	1.78	Medium	Herrera (2005)
Organic matter (%)	3.07	Medium	Tekalign *et al*. (1991) [28]
Total N (%)	0.2	Low	Landon (1991) [20]
Available P (mg/ kg^{-1})	25	Medium	Olsen and Dean (1965)
Available S (mg/ kg^{-1})	24.6	Medium	EthioSIS (2014) [10]
CEC (cmol kg^{-1})	77.5	High	Tekalign *et al*. (1991) [28]
Exchangeable K (cmol kg^{-1})	6.8	Medium	FAO (2006) [35]
Exchangeable Mg(cmol kg^{-1})	10.7	Medium	FAO (2006) [35]
Exchangeable Ca (cmol kg^{-1})	6.7	Medium	FAO (2006) [35]
Exchangeable Na (cmol kg^{-1})	3.02	Medium	FAO (2006) [35]

Total soil nitrogen was 0.2%, which is the low range as rated by London (1990) [20]. Therefore, the soil's total nitrogen level was insufficient for optimum crop growth and yield. The available phosphorous (P) of the soil was 25 ppm. According to the rating of Olsen and Dean (1965) [25], the level of available P was in the medium range. The available sulphur content of the soil was 24 mg kg^{-1}, and according to the rating of EthioSIS (2014) [10], it was in the medium range. The organic matter content of the soil was 3.07%, which is also in the medium range (Tekalign 1991) [28]. Cation exchanging capacity of the soil was 77.5 cmol kg^{-1}, which is rated as high (Tekalign 1991) [28]. Electrical conductivity of the soil was 1.94 ds/m and rated as medium (Tekalign 1991) [28].

Effect of intra row spacing and NPS fertilizer rate on phonological parameters of mung bean

The result of the analysis of variance revealed that the effects of intra-row spacing and NPS fertilizer rate were highly significant ($p < 0.01$) for a number of days to 50% flowering, but their interaction was not significant ($p > 0.05$). The earliest flowering (41.12 days) was observed for intra row spacing of 5 cm, while intra row spacing of 20 cm resulted in delayed flowering (43.9 days) (Table 2). On the other hand, the shortest duration (39.88 days) to reach 50% flowering was recorded for the unfertilized control plot, while the prolonged period (44.6 days) to 50% flowering was recorded for the application of 200 kg ha^{-1} of NPS (Table 2).

Table 2: Phonological, growth, nodule, yield and yield attributes of mung bean influenced by intra row spacing and NPS fertilizer rates in ARBA Minch district

Intra row spacing (plant ha^{-1})	DF	LA	PB	TN	EN	NSP	HSW
5	41.12^{d}	364.03^{c}	2.20^{d}	33.58^{a}	16.82^{a}	10.02^{c}	6.19^{d}
10	42.48^{c}	398.46^{c}	4.18^{c}	34.28^{a}	17.40^{a}	11.53^{b}	6.60^{c}
15	43.14^{b}	536.10^{b}	5.14^{b}	35.09^{a}	17.44^{a}	11.92^{b}	7.01^{b}
20	43.90^{a}	596.09^{a}	5.60^{a}	35.21^{a}	18.20^{a}	12.64^{a}	7.50^{a}
LSD (5%)	0.38	43.72	0.32	NS	NS	0.39	0.29
NPS (kg/ha)							
0	39.88^{e}	364.57^{d}	2.60^{e}	13.88^{e}	5.89^{e}	10.15^{d}	5.73^{e}
50	41.08^{d}	464.87^{c}	3.80^{d}	24.00^{d}	13.80^{d}	11.11^{c}	6.31^{d}
100	43.58^{c}	469.24^{bc}	4.70^{c}	41.35^{c}	21.11^{c}	12.63^{a}	7.59^{a}
150	44.16^{b}	517.38^{ab}	5.13^{b}	44.69^{b}	22.99^{b}	11.91^{b}	7.15^{b}
200	44.60^{a}	552.27^{a}	5.58^{a}	48.28^{a}	24.54^{a}	11.63^{bc}	6.80^{c}
Mean	42.66	473.67	4.32	34.04	17.47	11.53	6.72
LSD (5%)	0.43	48.88	0.36	2.78	1.54	0.44	0.29
CV (%)	1.23	12.49	10.11	9.9	10.73	4.68	5.3

DF = Days to Flowering; LA = Leaf Area; PB = Primary Branches; TN = Total Number of Nodules; EN = Effective Nodulation; NSP = Number of Seeds per Pod; HSW = Hundred Seed Weight. Means with the same letter (s) in a column are not significant at ($p \leq 0.05$).

Results also revealed that both intra row spacing and NPS fertilizer rate had highly significant ($p < 0.01$), and their interaction had a significant ($p < 0.05$) effect on the number of days to 90% physiological maturity. The shortest duration (62.46 days) to reach 90% physiological maturity was recorded for intra-row spacing of 5 cm with 0 kg of NPS ha^{-1}, whereas a prolonged period (72.86 days) to 90% physiological maturity was recorded for intra-row spacing of 20 cm with 200 kg NPS ha^{-1} (Table 3).

Effect of intra row spacing and NPS fertilizer rate on growth parameters of mung bean

The result of analysis of variance revealed that the effects of intra-row spacing and NPS fertilizer rate were highly significant ($p < 0.01$) effect on leaf area, but their interaction effects were non-significant ($p<0.01$) effect. The lowest leaf area (364.57 cm^2) was recorded at intra row spacing of 5 cm while highest leaf area (552.27 cm^2) was recorded at intra row spacing of 20 cm (Table 2). The lower leaf area (364.57 cm^2) was recorded for 0 kg NPS ha^{-1}, while the highest leaf area (552.27 cm^2) was recorded for 200 kg NPS ha^{-1}.In addition, leaf area index was highly significantly ($p < 0.01$) influenced by intra row spacing and NPS fertilize rates and by their interaction ($p < 0.05$). The highest leaf area index (2.24) was recorded at 5 cm intra row spaced with 200 kg NPS ha^{-1}, while the lowest value (0.57) was recorded for intra row spacing of 20 cm with 0 kg NPS ha^{-1} (Table 3).

The result indicated that both intra row spacing and NPS fertilizer rate and their interaction had highly significant ($p < 0.01$) and significant ($p < 0.05$) effects, respectively, on plant height (Table 3). The tallest height (71.77 cm) was recorded for intra-row spacing of 5 cm with 200 kg ha^{-1} of NPS, while the minimum value (43.96 cm) was recorded for intra-row spacing of 20 cm without NPS application. The result indicated that intra-row spacing and NPS fertilizer rate had a highly significant ($p < 0.01$) effect on the number of primary branches per plant, but their interaction was not significant ($p>0.05$). The highest number of primary branches per plant (5.6) was recorded for the wider intra row spacing (20 cm), while the lowest (2.2) was recorded for the closest spacing (5 cm). On the other hand, the highest number of primary branches (5.58) was recorded for the application of 200 kg ha^{-1} of NPS, while the lowest value (2.6) was for the unfertilized control plot (Table 2).

Effect of intra row spacing and NPS fertilizer rate on nodule parameters of mung bean

The analysis of variance showed that the effect of intra row spacing and its interaction with NPS rate was non-significant ($p > 0.05$), but NPS fertilizer rates had significant ($p<0.05$) effect on total number of nodules per plant. The highest number of nodules (48.28) was produced at 200 $kgha^{-1}$ of NPS, while the lowest value (13.88) was recorded for the unfertilized control plot (Table 2). Also, the effect of intra row spacing and its interaction with NPS rate was non-significant, but the application of NPS fertilizer had a significant ($p<0.05$) effect on the number of effective nodules per plant. The highest number of effective nodules (24.54) was recorded for the application of 200 kg ha^{-1} of NPS, while the lowest value (5.89) was for the unfertilized control treatment (Table 2).

Table 3: Phonological, growth, nodule, yield and yield attributes of mung bean influenced by intra row spacing and NPS fertilizer rates in ARBA Minch district

NPS rates (kg/ha)	Intra rows pacing (plant ha^{-1})	90% DM	LAI	PH	NPPP	AGBM	GY	HI
0	5 (500, 000)	62.46j	1.10def	62.18ef	23.26^{f}	4030.1^{hi}	685.4^{i}	17.01^{l}
	10 (250, 000)	65.26i	0.90ghijk	62.10ef	30.33^{e}	4343.1^{ghi}	1401.7^{f}	32.2^{fg}
	15 (166, 667)	68.1h	0.70lm	46.80ij	36.33^{d}	4342.4^{ghi}	1120.4^{h}	26.66^{ij}
	20 (125, 000)	68.3gh	0.57m	43.96j	37.76^{cd}	3130.3^{j}	569.9^{i}	18.16^{l}
50	5 (500, 000)	65.50i	1.79c	65.93cde	28.60^{e}	4879.3^{de}	1267.3^{fg}	25.9^{j}
	10 (250, 000)	68.73fgh	0.96efghi	65.567cde	36.60^{d}	5040.9^{cde}	1819.2^{c}	36.05^{cde}
	15 (166, 667)	69.53efgh	0.86hijkl	53.90gh	39.40^{bcd}	4386.6^{fgh}	1550.2^{e}	35.30^{cdef}
	20 (125, 000)	70.53bcde	0.74kl	49.33hi	42.53^{abc}	3937.3^{i}	1186.3^{gh}	30.06^{gh}
100	5 (500, 000)	68.20gh	1.93bc	69.267abc	31.60^{e}	5808.4^{ab}	1729.1^{cd}	29.73^{ghi}
	10 (250, 000)	69.33efgh	1.05efg	65.56cde	42.01^{abc}	5307.8^{bcd}	2245.5^{a}	42.28^{a}
	15 (166, 667)	70.2cdef	0.93fghij	63.40def	45.13^{a}	4880.0^{de}	2006.4^{bc}	41.10^{ab}
	20 (125, 000)	71.66abc	0.78jkl	54.40gh	43.80^{ab}	4653.7^{efg}	1570.2^{e}	33.72^{def}
150	5 (500, 000)	69.13efgh	2.02b	71.33abc	36.40^{d}	5864.3^{ab}	1574.6^{e}	26.8^{hij}
	10 (250, 000)	70.13cdef	1.11de	67.56bcd	41.20^{abcd}	5363.7^{bc}	2180.5^{ab}	40.6^{ab}
	15 (166, 667)	71.53abcd	0.96efghi	65.43cdef	42.0^{abc}	4903.8^{de}	1832.0^{c}	36.90^{cd}
	20 (125, 000)	72.26ab	0.80ijkl	57.86fg	44.10^{ab}	4660.1^{efg}	1540.3^{e}	33.0^{efg}
200	5 (500, 000)	69.86deefg	2.24a	71.77a	36.13^{d}	5937.1^{a}	1337.8^{f}	22.5^{k}
	10 (250, 000)	72.0ab	1.25d	68.60bcd	40.60^{bcd}	5570.3^{abc}	2101.8^{b}	37.70^{bc}
	15 (166, 667)	71.8abc	1.00efgh	65.40cdef	41.21^{abcd}	4936.6^{cde}	1625.2^{de}	32.19^{fg}
	20 (125, 000)	72.86a	0.82ijkl	61.56ef	43.13^{abc}	4804.9^{ef}	1272.5^{fg}	26.45^{ij}

DM = Days to Maturity; LA = Leaf Area Index; PH = Plant Height; NPPP = Number of Pods per Plant; AGBM = Above Ground Dry Biomass; GY = Grain Yield; HI = Harvest Index. Mean values followed by the same letter (s) with in the same column are not significantly different at 5%.

Effect of intra row spacing and NPS fertilizer rate on yield and yield components of mung bean

The analysis of variance revealed that both intra row spacing and NPS fertilize rate had highly significant ($p<0.01$) effect on number of pods per plant of mung bean, which also significantly ($p<0.05$) affected by the interaction of the two factors. The highest number of pods per plant (45.13) was recorded at intra row spacing of 15 cm with 100 kg NPS ha^{-1}, while intra row spacing of 5 cm with the application of 0 $kgha^{-1}$ of NPS resulted in the lowest value (23.26) (Table 3). The number of seeds per pod was also highly significantly ($p < 0.01$) affected by intra row spacing and NPS fertilize rate, but their interaction was non-significant (p> 0.05). The highest number of seeds per pod (12.64) was produced at the widest intra row spacing (20 cm), while the value (10.02) was for 5 cm. (Table 2). Similarly, application of 100 kgha^{-1} of NPS resulted in the highest number of seeds per pod (12.63), while the lowest value (10.15) was recorded for the unfertilized plot (Table 2).

The results also showed that the effect of intra row spacing and NPS rate was highly significant (p< 0.01), but their interaction was non-significant (p>0.05) for hundred seed weight of mung bean (Table 2). The highest hundred seed weight (7. 5 g) was recorded for intra row spacing of 20 cm, while the lowest value (6.19 g) was for intra row spacing of 5 cm. Application of 100 kg ha^{-1} of NPS resulted in the highest hundred seed weight (7.59 g), while the lowest value (5.73 g) was recorded for the plot maintained without NPS fertilizer (Table 2).

The analysis of variance revealed that the effect of intra row spacing and NPS fertilizer rate was highly significant (p< 0.01) effect on above ground dry biomass while their interaction was significant (p< 0.05) for above ground dry biomass yield of mung bean. The highest dry biomass yield (5957.1 kgha^{-1}) was produced at intra row spacing of 5 cm with 200 kg ha^{-1} of NPS, while the lowest (3130.3 kgha^{-1}) was recorded for intra row spacing of 20 cm without NPS application (Table 3). Also, the effect of intra row spacing and NPS fertilizer rate was highly significant (p< 0.01) for grain yield per hectare. Their interaction was also significant (p< 0.05) for the same parameter. The highest grain yield (2245.5 kg ha^{-1}) was recorded for intra row spacing of 10 cm with the application of 100 kg of NPS ha^{-1}, while the lowest (569.9 kg ha^{-1}) was obtained from intra row spacing of 20 cm with no application of NPS fertilizer (Table 3).

Harvest index was significantly affected by intra row spacing and NPS fertilize rate (p< 0.001) as well as by their interaction (p< 0.05). The highest harvest index (42.28%) was recorded for intra row spacing of 10 cm with the application of 100 kgha^{-1} of NPS fertilizer, which was statically similar with the value obtained at 15 cm with the same fertilizer rate, while the lowest harvest index (17.01%) was recorded for intra row spacing of 5 cm maintained without fertilizer (Table 3).

Pearson correlation analysis among traits

Number of branches per plant showed a positive and highly significant correlation with number of days to 50% flowering (r=0.93*), number of pods per plant (r=0.91**), and number of seeds per pod (r=0.74**), hundred seed weight (r=0.83**), aboveground dry biomass yield (r=30*) and grain yield (r = 48*), but negatively correlated with number of days to 90% physiological maturity (r=-0.94*). A positive and highly significant correlation existed between plant height (r = 91**) and the number of pods per plant. Similarly, a positive and highly significant correlation was observed for plant height and number of days to flowering (r = 0.57**), leaf area index (r = 0.95**), total number of nodules (r=0.82**), number of effective nodules (r=0.93**), number of primary branches per plant (r=0.37*), hundred seed weight (r =0.61**), above ground dry biomass yield (r = 94**) and grain yield (r =0.72**), but negative correlation to days to maturity (r= -0.55**).

Grain yield showed a positive and highly significant correlation with number of days to flowering (r = 0.64**), number of days to maturity (r = 0.62**), leaf area index (r = 0.72**), plant height (r = 72**), number of pods per plant (r=67**), number of seeds per pod (r=60**), hundred seed weight (r= 0.80**), above ground dry biomass yield (r=76**) and harvest index (r = 0.96**).

Table 4: Correlation coefficient between Phonological, growth, nodule, yield and yield parameters of mung bean

	DF	DM	LAI	PH	PB	TN	EN	NPP	NSP	HSW	BM	GY	HI
DF	1												
DM	-0.94**	1											
LAI	0.45*	-0.42*	1										
PH	0.57**	-0.55**	0.93**	1									
PB	-0.93**	0.94**	0.22*	0.37*	1								
TN	-0.72**	0.62**	0.83**	-0.82**	-0.51**	1							
EN	0.77**	0.7**	0.88**	0.93**	0.58**	0.91**	1						
NPP	-0.89**	0.91**	0.24*	0.76**	0.91**	0.6**	-0.54**	1					
NSP	0.77**	-0.77**	0.23*	0.63**	0.74**	0.54**	0.48*	0.85**	1				
HSW	0.93**	-0.84**	0.56**	0.61**	0.83**	0.87**	0.8**	0.87**	0.74**	1			
BM	0.4*	0.39*	0.97**	0.94**	0.30*	0.82**	0.85**	0.27*	0.23*	0.53*	1		
GY	0.64**	0.62**	0.72**	0.72**	0.48*	0.9**	0.76**	0.67**	0.6**	0.8**	0.76**	1	
HI	0.65**	-0.65**	0.54*	0.56*	0.56**	0.81**	-0.62**	0.77**	0.66**	0.8**	-0.57**	0.96**	1

* And ** correlation is significant at 0.05 (p< 0.05) and 0.01 (p< 0.01) probability levels respectively. DF= number of days to 50% Flowering; PM= number of days to 90% physiological maturity; PB= total number of primary branches per plant; PH=plant height; TN= Total number of nodules; EN=Number of effective nodulation; NPP =Number of pods per plant; NSP =number of seeds per pod; BM = aboveground dry biomass yield; *GY* = Grain Yield; HSW= hundred seed weight and HI= harvest index.

Economic Analysis

A cost-benefit analysis was undertaken for different fertilizer treatments to determine the highest net benefit with an acceptable, marginal rate of return (Table 5). Accordingly, unit cost of fertilizer unit cost of seed were taken as variable costs, fertilizer cost, unit labor cost of planting and unit quantities of price of mung bean at local condition was taken as value of crop all were as variable costs. Before calculating value-cost and benefit - cost ratio, grain yield was adjusted to 10% reduction to reduce extrapolation error. Gross benefit of the treatments was calculated using the adjusted yield and the field gate price of the crop. In contrast, net benefit was calculated by subtracting variable costs from the gross benefit of each treatment. Accordingly, the highest net benefit (56585.8 Birr ha^{-1}) was obtained from the treatment combination of 100 kg of NPS ha^{-1} and intra row spacing of 10 cm, while the lowest net benefit (15267 Birr ha^{-1}) was obtained from the treatment combination of 200 kg of NPS ha^{-1} and intra row spacing of 20 cm. The highest marginal rate of return

(MRR) (2928.4%) was obtained from the treatment combination of 100 kg NPS ha^{-1} and intra row spacing of 10 cm (Table 14). Therefore, the best alternative return, the above-mentioned fertilizer rate is recommended as best economically treatment was (intra row spacing 10 cm) with (100 kg ha^{-1}) for the study area (Table 4).

Table 4: Summary of partial budget analysis of response of mung bean to NPS rate and intra row spacing

Treatments combinations (cm, kg ha^{-1})	Unadjy	Adjy (0.10)	TRN (Birr ha^{-1})	CS (BirKg^{-1})	CF (Birkg^{-1})	LCFA (Birrha^{-1})	LCP (Birr ha^{-1})	TVC	NEB (Birrha^{-1})	MRR%
20 cm, 0 kgha^{-1} NPS	569.9	512.9	15387	120	0	0	720	840	15267	-
15 cm, 0 kgha^{-1} NPS	1120.3	1008.36	30250.8	180	0	0	1200	1380	28870.8	2519.2
10 cm, 0 kgha^{-1} NPS	1401.7	1261.53	37845.9	240	0	0	1800	2040	35805.9	1050.7
20 cm, 50 kgha^{-1} NPS	1186.1	1067.49	32024.7	120	700	600	720	2140	31104.7	D
15 cm, 50 kgha^{-1} NPS	1550.2	1395.18	41855.4	180	700	600	1200	2680	39175.4	1494.5
20 cm, 100 kgha^{-1} NPS	1570.1	1413.18	42395.4	120	1400	600	720	2840	40775.4	1000
5 cm, 0 kgha^{-1} NPS	685.3	616.68	18500.4	480	0	0	2400	2880	15620.4	D
10 cm, 50 kgha^{-1} NPS	1819.2	1637.55	49126.5	240	700	600	1800	3340	45786.5	1002.2
15 cm, 100 kgha^{-1} NPS	2086.3	1877.76	56332.8	180	1400	600	1200	3380	54652.8	2216.7
20 cm, 150 kgha^{-1} NPS	1540.3	1386.27	41588.1	120	2100	600	720	3540	39268.1	D
10 cm, 100 kgha^{-1} NPS	2245.4	2020.86	60625.8	240	1400	600	1800	4040	56585.8	2928.4
15 cm, 150 kgha^{-1} NPS	1832	1648.8	49464	180	2100	600	1200	4080	47084	D
5 cm, 50 kgha^{-1} NPS	1267.2	1140.57	34217.1	480	700	600	2400	4180	30037.1	D
20 cm, 200 kgha^{-1} NPS	1272.5	1145.25	34357.5	120	2800	600	720	4240	31337.5	D
10 cm, 150 kgha^{-1} NPS	2184.1	1965.69	58970.7	240	2100	600	1800	4740	54230.7	D
15 cm, 200 kgha^{-1} NPS	1625.2	1462.68	43880.4	180	2800	600	1200	4780	40800.4	D
5 cm, 100 kgha^{-1} NPS	1729.1	1556.19	46685.7	480	1400	600	2400	4880	41805.7	D
10 cm, 200 kgha^{-1} NPS	2101.7	1891.53	56994	240	2800	600	1800	5440	51554	D
5 cm, 150 kgha^{-1} NPS	1574.6	1417.14	42514.2	480	2100	600	2400	5580	36934.2	D
5 cm, 200 kgha^{-1} NPS	1337.8	1204.02	36120.6	480	2800	600	2400	6280	29840.6	D

Audj = adjusted yield, AjY = adjusted grain yields = cost of seed (24, 12, 9, 6 kgha^{-1}) =20 birrkg^{-1}, TVC = Total variable cost, PQ price of quantity 30 birr, TRN = Total rate revenue, NB = Net benefit, MRR = Marginal rate of return. The price of 1kg NPS was 14 E Birr-kg$^{-1,}$ Labour Fertilizer application cost = 120 Birr ha^{-1} (5 person per a day), Labour for planting =120 birrha^{-1} (20, 15, 10, 6 person per a day).

Discussion

In Ethiopia, several biotic and abiotic factors lead to decreased yield of mung bean (Das *et al*. 2014) [5]. The major reasons for its low yield are the limited experience of farmers in its production practices, as it is a recently introduced crop which is not well known in the area, less interest of farmers to produce, limited use of inputs, including inappropriate agronomic practices, inadequate or imbalanced fertilizer application and irregular planting spaces as a result of broad casting, lack of improved varieties, and diseases and pests (Hasanuzzaman *et al*. 2013; Fanuel and Walelign 2013) [15, 11]. The present study showed that interaction effect of intra-row spacing and NPS fertilizer rate was highly significant (p< 0.01) for days to 90% physiological maturity, but their interaction was not significant (p> 0.05) for days to 50% flowering. The earliest flowering and shortest duration to reach 90% physiological maturity were observed for narrow intra row spacing with no NPS ha$^{-1.}$ The possible reason might be due to high competition among plants for growth resources that led to early formation of reproductive parts. This result was in line with the findings of Asaye *et al*. (2018) [2], who reported early flowering with intra row spacing of 5 cm in mung bean. Other consistent findings of Gezahegn *et al*. (2021) [13] and Nuru (2021) [24] indicated that increased NPS rates (150 kgha^{-1} NPS) resulted in the longest duration to maturity. The lowest leaf area but increase in LAI with narrow intra-row spacing at narrow intra-row spacing plus the highest NPS rate might be due to the production of more leaves with more expanded area in response to the supply of more nitrogen from increased NPS rate. This result was in agreement with the findings of Masa (2017) [21], who reported that LAI increased as intra row spacing decreased (5 cm) and vice versa (15 cm) in mung bean and common bean, respectively.

The height of plant showed tallest at narrow intra row spacing, whereas highest number of primary branches per plant was recorded for the wider intra row spacing. On the other hand, the highest number of primary branches was recorded for application of higher N amount of NPS, while the lowest value was for the unfertilized control plot. The increase in a number of primary branches at higher NPS rates might be due to an adequate supply of nitrogen, which is responsible for vegetative growth. Both number of nodules and number of effective nodules were highest at highest amount of NPS, while the lowest value was recorded for the unfertilized control plot**.** The increase in a number of effective nodules with an increasing rate of NPS application might be associated with increased supply and plant uptake of phosphorus and sulfur that stimulates active nodule formation and enhances the yield of mung bean. Similarly, Adugna *et al*. (2020) [1] and Deresa (2018) [6] have reported that the highest total number of nodules per plant of mung bean and common bean, respectively, was recorded for application of the highest rate of NPS (200 kgha^{-1}), while the lowest value was recorded for the control plot. Also, the increase in a number of seeds per pod at the widest intra-row spacing might be because of less competition for resources and, probably, an increased rate of dry matter partitioning to reproductive parts. In agreement with the current result, Gebrelibanose and Fisha (2018) [12] have reported that wider intra row spacing (20 cm) of mung bean resulted in the highest numbers of seeds. The grain yield of 2245.5 kg ha^{-1} was recorded for intra row spacing of 10 cm with application of 100 kg of NPS ha^{-1}, while the lowest grain yield (569.9 kg ha^{-1}) was obtained from intra row spacing of 20 cm with no application of NPS fertilizer. The highest harvest index (42.28%) was recorded for intra row spacing of 10 cm with the application of 100 kgha^{-1} of NPS fertilizer, which was statically similar with the value obtained at 15 cm with the same fertilizer rate, while the lowest harvest index (17.01%) was recorded for intra row spacing of 5 cm maintained without fertilizer.

Conclusion
Our study revealed that the effect of intra row spacing and NPS fertilizer rate was highly significant ($p \leq 0.01$) for the number of days to 50% flowering, number of primary branches, total number of nodules, number of effective nodules, number of seeds per pod and hundred seed weight. Moreover, the interaction of intra row spacing and NPS rate significantly affected the number of days to 90% physiological maturity, leaf area index, plant height, number of pods per plant, above ground dry biomass yield, grain yield and harvest index. Besides, all yield-related parameters also showed significant and positive correlations with grain yield. Results of partial budget analysis showed that the highest net benefit (56585.8 Birr ha^{-1}) with an acceptable marginal rate of return (2928.4%) was obtained from the combination of 10 cm intra row spacing and application of 100 kg of NPS ha^{-1}. In general, the study recommends that intra row spacing of 10 cm with application of 100 kg ha^{-1} of NPS fertilizer would offer the highest grain yield, MRR and net benefit to growers of mung bean in the study district and other similar agro-ecology.

Declaration of Competing Interest
The authors have no conflict of interest.

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This manuscript is extracted from the thematic research undertaken by the Department of Plant Science, College of Agricultural Sciences, ARBA Minch University. The data is available in the college's MSc thesis report.

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