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Performance of Mung Bean (*Vigna radiata* L. Wilczek) Influenced by Plant Population and NPS Fertilizer Rates in Bako

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Mung bean (*Vigna radiata* L.*)* is a leguminous crop with a tremendous potential in achieving food and nutritional security in Ethiopia in future. In addition, mung bean plays a major role in improving soil nitrogen content through atmospheric nitrogen fixation, thus reducing the dependance on synthetic nitrogenous fertilizers. However, its productivity is limited by inadequate plant population and NPS fertilizer rate in the study area. Hence, this study was carried out to determine the optimum plant population and NPS fertilizer rates for mung bean borda variety in Bako. The experiment comprised of factorial combinations of four different plant populations (500000, 571429, 666667, and 800000 plants ha^{-1}) and five NPS fertilizer rates (0, 50, 100, 150 and 200 kg ha^{-1}) and it was laid out using Randomised Complete Block Design with three replications. Results indicated that main effect of plant population and NPS fertilizer rates had significant effect on phenology, growth, yield, and yield components of mung bean, except stand count, above-ground biomass, straw and seed yield, which were affected by the main factors and their interactions. Highest nodule dry weight per plant (0.14g), number of pods per plant (4.74 g), weight of seeds per pod (10.26 g), 100-seed weight

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(3.61g), and harvest index (31.16%) were observed under minimum plant population (500,000 plants ha^{-1}). Moreover, effective nodules per plant (2.28), nodule fresh weight (0.33 gm), nodule dry weight (0.141g plant^{-1}), number of pods per plant (4.79), seeds per pod (10.78 g), 100-seed weight (3.73 g) and harvest index (32.98%) were observed under 200 kg ha^{-1} NPS fertilizer rate. Highest stand count per hectare (780,667 plants ha^{-1}), above-ground biomass (4,947kg ha^{-1}), seed yield ha^{-1} (1,371kg ha^{-1}) and straw yield (3,575 kg ha^{-1}) were recorded at higher plant population (800,000 plants ha^{-1}) with 200kg NPS ha^{-1} fertilizer rate. However, higher plant population (800,000 plants ha^{-1}) at the rate of 100 kg NPS ha^{-1} fertilizer produced1, 325 kg ha^{-1}seed yield which was the highest net benefit (50,080 TB) and marginal rate of returns (5,610.8%). Therefore, application of 100 kg NPS ha^{-1} fertilizer rate with plant population of 800,000 plants ha^{-1} can be recommended for mung bean production in the study area and similar agro-ecologies. However, the current study was carried out only in one location for one cropping season, hence further studies over many seasons and across several locations are needed to have a conclusive recommendation for wide range of agro-ecologies for mung bean production.

Keywords: Mung bean; plant population; NPS fertilizer rates.

1. INTRODUCTION

Mung bean (*Vigna radiata* L. Wilczek) is a recently introduced pulse crop in Ethiopia, it covers 41,633.20 hectares area and produces 514, 22.741 tons with average productivity of 1.235 tons ha^{-1} [1]. Mung bean is a short-duration grain legume crop with wide adaptability, low input requirements, and ability to meliorate the soil by fixing atmospheric nitrogen. It is the suitable and recommended pulse crop to improve the nation's food insecurity and enhance soil fertility in Ethiopia [2].

Application of NPS fertilizer and optimum plant population (plants ha^{-1}) increase yield and yield components of mung bean [3]. Relatively small amount of nitrogen fertilizer application induces rhizobia and promotes growth of strong mung bean seedlings. During the early growth period, it promotes vegetative growth and creates conditions favoring high yield [4]. Application of phosphorus plays an important role in growth, development, and yield productivity of mung beans [5,6]. It helps to enhance grain yield, seed quality, regulate the photosynthesis, govern physiological and biochemical processes as well as the development of roots and nodulation which facilitates nitrogen fixation [7]. Similarly application of sulfur significantly improves development of nodules, plant height, days to mature, dry weight, pods per plant and test weight and as a result maximum seed yield per plant or per hectare is achieved [8]. Optimum plant population or proper space between plants and between rows improves mung bean yield [9]. Farmers may have the opportunity to decrease seed rate, labor cost and increase mung bean yield and ultimately improve their livelihoods through adopting appropriate plant population [10]. Objectives of the experiment were to assess the effect of plant population, to evaluate the effect of NPS fertilizer rates and to determine economically optimal plant population and NPS fertilizer rates of mung bean.

2. MATERIALS AND METHODS

The experiment was carried out during the main cropping season (July to September) of 2020 at Bako Agricultural Research Center (BARC) which is located in western Ethiopia. It is located at an altitude of 1650 m above sea level and 09^{o} 6'00" N latitude and 37^{o} 09'00"E longitude. Mean annual rainfall of Bako from January to December was 1332 mm with warm humid climate having mean minimum, mean maximum and average atmospheric temperatures of 13.7^{o}C, 28.7^{o}C and 21.1^{o}C, respectively (Meteorological station of the Bako Agricultural Research Center, 2019) The predominant soil type of the area was Nitosols which was characteristically reddish brown and clay in texture with a pH that falls in the range of very strongly acidic to strongly acidic (4.8-5.8) according to rating done by Benton (2003).

Mung bean borda variety released by Hawassa Agricultural Research Center in 2008 was used as a test crop. The variety is adapted to areas having 1000-1650 m elevation, with 350-750mm annual rainfall. It is an early maturing variety requiring 70-80 days to mature and have average productivity of 1.3-2.0 and 0.5-1.0 tones ha^{-1} yield under research field and under farmer field respectively. NPS fertilizer with N 19%, P 38%, and S 7%) was used for the experiment.

The treatments consisted of four levels of plant population (500000, 571429, 666667, and 800000 plants ha^{-1}) and five NPS fertilizer rates (0, 50, 100, 150, and 200 kg ha^{-1}). The treatments were arranged in a 4*5 factorial experiments and laid out in Randomized Completely Block Design (RCBD) with three replications. Thus, there were a total of twenty treatment combinations. Plot size was 3m x 1.8m with 5.4m^{-2} areas. Spacing between plots and blocks were 0.6 m and 1.5m, respectively and total experimental area was 47.4m x 12m (568.8m^2). Outside rows sharing borders with other treatment plots were not considered for recording observations due to border effect and the adjacent inside rows from both sides were used for sampling.

The experimental field was plowed once, harrowed and then leveled to make it suitable for sowing. The seeds were sown in the rows; and the spacing between rows and plants were 40cm*5cm, 35cm*5cm, 30cm*5cm, and 25cm*5cm for 500000, 571429, 666667, and 800000 plant populations ha^{-1}, respectively. The NPS fertilizer was applied at sowing time as per the treatments by band method of application. Two seeds were sown per hill which was thinned to one after 10 days of emergence. Two times hand weeding was applied one at 10 days after emergence and second at 40 days after emergence. All other agronomic practices were carried out uniformly for all plots. The crop was harvested at maturity manually from each plot from the central rows when the bottom of the mung bean pods started to dry and threshing was done manually and separately for each plot.

3. DATA COLLECTED AND MEASUREMENTS

Days to 50% emergence: It was recorded as number of days from date of sowing to the time when 50% of the seeds emerged in each plot from the ground.

Days to 50% flowering: It was determined by counting the number of days from planting to the time when first flowers appeared in 50% of the plants in a plot.

Days to physiological maturity: It was determined as the number of days from planting to the time when 90% of the plants started senescence of leaves (yellowing of the foliage) and pods started to lose its pigmentation.

Number of total nodules per plant: From destructive rows in each plot, bulk root of 10 randomly selected plants were taken carefully at the age of 50% flowering and uprooted for nodulation study. Roots were carefully washed using tap water on a sieve and total nodules were separated and counted.

Number of effective nodules per plant: For determination of effective number of nodules, the inside color of nodules were observed by cutting each nodule with the help of sharp blade and the pink colored nodules were considered as effective nodules, while green/white colored nodules were considered as non-effective.

Nodule fresh weight plant^{-1}: The nodules collected from ten plants from each plot were pooled including the dissected nodules for color determination, and their fresh weight is measured by sensitive balance to constant weight.

Nodule dry weight plant^{-1}: It was measured after ten sample plant roots nodules oven dried at 70 ^{0}C for 48 hours, then dry weight was measured by sensitive balance to constant weight and expressed as an average of ten plants that reported in gram per plant.

Plant height (cm): It was measured at physiological maturity from the base to the tip of a plant for randomly pre-tagged ten plants in harvestable rows using meter tape and averaged on a plant basis.

Number of primary branches per plant: It was determined by counting the total number of branches on randomly pre-tagged ten plants in the net plot at physiological maturity and averaged per plant basis.

Number of secondary branches per plant: The numbers of branches arising from the primary branches were counted at the time of physiological maturity for 10 randomly pre-tagged plants and the average was recorded per plant basis.

Number of leaves per plant: It was determined as the total number of leaves at flowering and at physiological maturity from10 randomly pre-tagged plants per plot and the average was recorded per plant basis.

Tap root length (cm): Taproot length was measure from the ground level to the tip of root from randomly selecting ten plants of destructive rows.

Plant stand count: Number of plants from harvestable plot area (net plot area) were counted at harvesting and converted to hectare basis.

Number of pods per plant: It was recorded from 10 pre-tagged plants in each net plot area at harvest and the average was taken as number of pods per plant.

Number of seeds per pod: Total number of seeds in the pods of the ten plants were counted and divided by the total number of pods to find the number of seeds on pod.

Hundred seed weight (g): Weight of randomly selected 100 seeds were determined for each plot using a sensitive balance.

Above ground dry biomass yield (kg ha^{-1}): To determine aboveground dry biomass yield, above ground dry biomass were measured after harvested and dried in the field for seven days.

Grain yield (kg ha^{-1}): Grain yield was measured by harvesting the crop from the net plot area and the weight was adjusted at 10 % moisture content and converted to kg ha^{-1}.

Harvest Index (HI): Harvest index calculated by dividing grain yield per plot adjusted to 10% moisture content by the sun-dried total above ground dry biomass yield per plot.

$$\mathrm{HI}\ (\%) = \left(\frac{\text{Grain Yield}}{\text{Aboveground dry biomass}}\right) * 100$$

Straw yield: Straw yield was determined after threshing and measuring the seed yield, the straw yield was measured by subtracting the seed yield from the total above ground biomass yield and converted in to kg ha^{-1}.

The collected data were subjected to analysis of variance (ANOVA) appropriate for factorial experiment in RCBD according to the General Linear Model (GLM) procedure of SAS version 9.0 (SAS Institute, 2004). Effects of the treatments were compared using least significance difference (LSD) test at 5% level of significance.

To compare the economic feasibility of the treatments, economic analysis was used as described by CIMMYT, [11].This analysis was performed in order to evaluate the economic feasibility of the treatments at the minimum rate of return 50 to 100 % [11]. Seed and straw yields of mung bean from experimental plots were adjusted 10% downward for management and plot size differences to regulate the difference between the experimental yield and the yield that farmers could expect from the same treatment. Fertilizer application cost (200 ETB per 100kg ha^{-1}), NPS fertilizer cost (15.64 ETB kg^{-1}), mung bean seed cost (45 ETB kg^{-1}), and seed sowing cost (30 ETBkg^{-1}) were used to obtain variable cost for this analysis. The current mung bean seed local price (40 ETBkg^{-1}) and straw selling price (2 ETB kg^{-1}) were used for the economic analysis.

4. RESULTS AND DISCUSSION

4.1 Number of Pods per Plant

The analysis of variance indicated that the main effect of NPS fertilizer rates and plant population had highly significant effect (P<0.01) on number of pods per plant, while their interaction had non-significant (P<0.05) (Table 1).

The highest number of pods per plant (4.74) was recorded under minimum plant population (500,000 plants ha^{-1}), while the lowest number of pods per plant (4.39) recorded under maximum plant population (800,000 plants ha^{-1}) (Table 1). With increased plant population ha^{-1}, progressively decreased number of pods per plant; that might be due to higher competitions between plants for growth requirements which are capable to decreased number of pod bearing branches that causes low yield per plant. Similarly Birhanu et al. [10] reported that the highest number of pods per plant from minimum plant population, while the lowest number of pods per plant was from maximum plant population of mung bean.

Application of the highest NPS fertilizer rates (200 kg ha^{-1}), produced highest number of pods per plant (4.79), while control treatment (0 kg NPS fertilizer ha^{-1}) produced the lowest number of pods (4.28) (Table 1). This might be due to adequate availability of N, P, and S, nutrients which might have facilitated the production of more branches and better canopy coverage, which might, in turn, have contributed for the production of higher number of total pods. This result agreed with Shanko et al. [12] who obtained the highest number of pods per plant at the highest rate of application of NPS fertilizer. Similarly, Deresa et al. [12] pointed out that the increase in number of pods per plant with the increased NPS rates.

Table 1. Main effects of plant population and NPS fertilizer rates on yield and yield components of mung bean

Treatments	Pod per plant	Seed per pod	Hundred Grain weight (g)	Harvest Index (%)
Plant population ha^{-1}				
500,000	4.74^{a}	10.27^{a}	3.61^{a}	31.16^{a}
571,429	4.63^{ab}	10.03^{ab}	3.52^{b}	30.8^{ab}
666,667	4.50^{ab}	9.80^{ab}	3.51^{b}	29.88^{b}
800,000	4.39^{b}	9.51^{b}	3.46^{b}	25.93^{c}
Mean	4.56	9.92	3.53	29.44
LSD(0.05)	0.25	0.52	0.06	1.42
0	4.23^{c}	8.89^{c}	3.11^{c}	24.97^{d}
50	4.44^{bc}	9.29^{c}	3.53^{b}	26.3^{c}
100	4.58^{ab}	10.04^{b}	3.59^{b}	30.24^{b}
150	4.73^{ab}	10.51^{ab}	3.69^{a}	32.74^{a}
200	4.79^{a}	10.78^{a}	3.73^{a}	32.98a
Mean	4.56	9.90	3.53	29.45
LSD(0.05)	0.28	0.58	0.07	1.29
CV (%)	7.50	7.00	2.30	5.30

Where, LSD: Least significant difference, CV: coefficient of variation, Values followed by the same letter(s) within the column are not significantly different at 0.05 probability level.

4.2 Number of Seeds per Pod

The analysis of variance indicated that the main effect of plant population had significant effect (P<0.05), the main effect of NPS fertilizer rates had highly significant effect (P<0.001) and their interaction had non-significant effect (P<0.05) on number of seed per plant (Table 1).

As plant population ha^{-1} increased, number of seeds per pods also decreased. The highest seeds per pods (10.26 g) were recorded under minimum plant populations, while the lowest seeds per pods (9.90 g) recorded under maximum plant populations (800,000 plants ha^{-1}) (Table 1).This might be attributed due to higher competitions between plants for growth requirements which are capable to increase number of pod bearing branches that causes high yield per plant. Similarly Birhanu *et al*. (2018) reported that the highest number of pod per plant from minimum plant population.

Application of higher NPS fertilizer (200kgha^{-1}) was produced the highest number of seed per pod (10.78g) which was statistically similar with 150 kg NPS fertilizer rate ha^{-1}, while the control (0kg NPS ha^{-1}) treatment produced the lowest number of seed per pod (8.89g) (Table 1). The increment in number of seeds per pod with increasing NPS fertilizer application rates might be due to the fact that phosphorus is an essential component in seed formation. Furthermore, the supply of adequate nutrients might have facilitated the vegetative growth, which might, in turn, have contributed for the production of higher number of seed per pod [13]. Similarly Nuru [14] observed the highest number of pod at the highest rates of NPS (150 kgha^{-1}) that might be attributed by the fact that NPS enhance establishment of beans, promote the formation of nodes, canopy development, and pod setting. In line with this finding, Baza [15] also observed significant variation in number of seeds per pod due to effect of NPS levels and mung bean.

4.3 Hundred Seed Weight (g)

The analysis of variance indicated that the main effect of plant population and NPS fertilizer rates had highly significant effect (P<0.001) on hundred Seed Weight, while their interaction was non-significant (Table 1).

The highest number of 100-seed weight (3.61 g) was recorded under minimum plant population (500,000 plants ha^{-1}) while the lowest number of 100-seed weight (3.46g) was recorded under maximum plant population (800,000 plants ha^{-1}) (Table 1). This might be due to the strong competition for moisture, light, and soil nutrients in higher plant population. The increase in seed weight might be due to availability of more resources at lowest plant population. This research result was in conformity with the previous finding of Kabir and Sarkar (2008), who reported that there is a significant difference in thousand grain weight of mung bean by the effect of row spacing. Similarly Abayneh [16] observed that the highest thousand grain weights (35.44 g) at highest plant population and the lowest thousand grain weight (33.04 g) at lowest plant population.

Application of 200kg NPS ha^{-1} produced significantly greater 100-seed weight (3.73g) as compared to the control plot (3.11g); however it was statistically at par with the application of 150 kg NPS fertilizer rate ha^{-1} (Table 1). As the NPS fertilizer application rate increased, hundred seed weight also increased proportionally. The increased in seed weight with increased rates of NPS fertilizer could be due to the fact that legumes especially mung bean have high phosphorus requirement as the main storage site of phosphorus in seed. Nuru [14] also reported similar findings in mung bean research conducted in Ethiopia. This might be also because of nutrient use efficiency by crop enhanced with level of NPS increased, since seed weight indicates the amount of resource utilized during critical growth periods in addition, to the supply of phosphorus that increase the formation of seed. Moreover, better growth and development of crop plants due to S supply and N uptake might have increased the supply of assimilates to seed, which ultimately gained more weight. Deresa *et al*. [12] also reported that the significant effect of blended fertilizer rates on 100-seed weight.

4.4 Harvest Index (HI)

The analysis of variance indicated that the main effect of plant population and NPS fertilizer rates had highly significant ($P<0.001$) effect on harvest index, while their interaction was non-significant ($P<0.05$) (Table 1).

The highest harvest index (31.16%) was recorded under minimum plant populations (500,000 plants ha^{-1}), while the lowest harvest index (25.93%) was recorded under maximum plant population (800,000 plants ha^{-1}) (Table 2). The decreased harvest index with increased plant density might be due to the increased competition in high densities for resource; and it was also related with size of seed in low population than in high population. Moreover, the lowest harvest index was mainly due to increased biomass yield rather than seed yield which lead to a decrease of harvest index. Similarly Habtamu *et al*., 2018 observed that the highest harvest index at low plant population and the lowest harvest index at the highest plant population.

The highest harvest index (32.98%) was recorded under 200 kg ha^{-1} NPS fertilizer rate which was statistically at parity with 150kgha^{-1} NPS (32.74%), while the lowest (24.97%) was recorded under control treatment (0 kg ha^{-1} NPS) (Table 2). This might be due to the influence of increased rate of NPS on translocation of dry matter from vegetative part to economic yield. This result agreed with Nuru, [14] reported that increase in harvest index with an increase of NPS fertilizer rate from 0 to 150kg NPS ha^{-1}. Similarly, Kaysha *et al.* [17] reported that the maximum harvest index (37.99%) from 200 kg $ha^{-1}$and minimum from control (27.23%).

4.5 Stand Count

The analysis of variance indicated that the main effect of NPS fertilizer rates and plant population as well as their interactions had highly significant effect ($P<0.001$) on stand count (Table 2).

Table 2. Interaction effects of plant population and NPS fertilizer rates on stand count of mung bean

Plant population (plants ha^{-1})					
NPS (kg^{-1})	500,000	571,429	666,667	800,000	Mean
0	472667^{gf}	493572^{gf}	540000^{de}	646000^{c}	538060
50	476000^{gf}	527143^{f}	573333^{d}	680000^{b}	564119
100	487667^{g}	542857^{def}	626667^{c}	760000^{a}	604298
150	489333^{g}	553238^{def}	633333^{c}	768000^{a}	610976
200	495267^{g}	560000^{de}	653333^{cb}	780667^{a}	622317
Mean	484187	535362	605333	726933	
LSD(0.05)	Population	NPS	Population* NPS		
	12844.1	14360.1	28720.2		
CV (%)	3.00				

Where: LSD: Least significant difference, CV: coefficient of variation, Values followed by the different letter(s) within the column is not significantly different at 0.05 probability level.

The highest stand count per hectare (780,667 plants ha^{-1}) was obtained at highest plant population (800,000 plants ha^{-1}) from the plots with the highest NPS fertilizer rate (200kg ha^{-1}),which was statistically at par with 800,000 plant populations ha^{-1}; received 100 and 150 kg NPS ha^{-1} fertilizer rate, while the lowest stand count (472,667plants ha^{-1}) was obtained at lowest highest plant population (500,000 plants ha^{-1}) from the plots with control NPS fertilizer rate, which was statistically at par with 500,000 plant populations ha^{-1}; received control treatment and 500,000 plant populations ha^{-1}; received 50kgha^{-1} NPS (Table 2). As plant population and NPS fertilizer rate increased, stand count also increased. This might be due to higher plant density and the increased NPS level that improves plants survival, plants growth and development through better up take of all nutrients, increased translocations photosynthetic materials, and reduce the mortality of plants due to competition for nutrient which in turn resulted in increased stand count. Moreover, the individual increment of different doses of NPS fertilizers had positive effect on the crop stand count which decreased the proportion of mortality rate of the plant due to competition. This result was in agreement with Abayneh [16] who reported that higher stand count per hectare was significantly increased with increased plant density.

4.6 Above Ground Dry Biomass Yield (kg ha^{-1})

The analysis of variance indicated that the main effect of plant population, the main effect of NPS fertilizer rates and their interactions had highly significant at ($P<0.001$ and $P<0.01$) on above-ground biomass yield, respectively (Table 3).

The highest above-ground biomass (4,947 kg ha^{-1}) was recorded under higher plant population (800,000 plants ha^{-1}) with highest NPS fertilizer rate (200kg ha^{-1}) which was statistically at par with 800,000 plants ha^{-1} which was received 100 and 150 kg NPS ha^{-1}, while the lowest above-ground biomass (2,406kg) was recorded under lower plant population (500,000 plants ha^{-1}) with lowest NPS fertilizer rate (0kg NPS ha^{-1}) which was statistically at par with 571,429 plants ha^{-1}; received control treatment (0 kg NPS ha^{-1})(Table 3). This could be due to high seed yield, number of seed per pod and plant height in the treatment of highest plant population density and highest NPS fertilizer rate. The added phosphorus might be essential in most metabolic processes include: energy generation, nucleic acid synthesis, photosynthesis, respiration, glycolysis, membrane synthesis and integrity, enzymatic activation or inactivation, redox reactions, signaling and carbohydrate metabolism that leads to the enhancement of dry biomass yield. In agreement with this finding, Kaysha *et al*. [17] reported that interactions of NPS fertilizer application with plant population significantly influenced above-ground dry biomass yield. Moreover, this finding was in conformity with the study of Kazemi *et al*. [18] who reported that more biomass was produced at higher plant population than lower plant population.

4.7 Seed Yield (kg ha^{-1})

The analysis of variance indicated that the main factors plant population and NPS fertilizer rates, and their interactions had highly significant effect ($P<0.001$ and $P<0.01$) on seed yield ha^{-1}, respectively (Table 4).

Table 3. Interaction effects of plant population and NPS fertilizer rates on above ground dry biomass yield of mung bean

Plant population (plants ha^{-1})					
NPS (kg-1)	500,000	571,429	666,667	800,000	Mean
0	2406^{k}	2457^{k}	2903^{ij}	3229^{fg}	2748.75
50	2716^{j}	2971^{hi}	3395^{ef}	3996^{b}	3269.5
100	3122^{ghi}	3205^{fgh}	3633de	4844^{a}	3701
150	3618de	3722^{cd}	3829^{bcd}	4887^{a}	4014
200	3766^{bcd}	3847^{bcd}	3930^{bc}	4947^{a}	4122.5
Mean	3125.6	3240.4	3538	4380.6	
LSD(0.05)	Population		NPS		population* NPS
	105.40		117.90		235.80
CV (%)	4.00				

Where: LSD: Least significant difference, CV: coefficient of variation and Values following by the different letter(s) within the column are not significantly different at 0.05 probability level.

Table 4. Interaction effects of plant population and NPS fertilizer rates on seed yield of mung bean

	Plant population (plants ha^{-1})				
NPS (kg ha^{-1})	500,000	571,429	666,667	800,000	Mean
0	646^{f}	658^{f}	686^{f}	730^{ef}	680
50	741^{ef}	800^{e}	905^{d}	972^{d}	854.5
100	980^{d}	996^{d}	1126^{c}	1325^{ab}	1106.75
150	1263^{b}	1283^{b}	1299^{ab}	1348^{ab}	1298.25
200	1330^{ab}	1335^{ab}	1341^{ab}	1371^{a}	1344.25
Mean	992	1014.4	1071.4	1149.2	
LSD(0.05)	Population	NPS		population* NPS	
	41.29	46.17		92.33	
CV (%)	5.3				

Where: LSD: Least significant difference, CV: coefficient of variation, Values followed by the different letter(s) within the column are not significantly different at 0.05 probability level.

Table 5. Interaction effects of plant population and NPS fertilizer rates on straw yield of mung bean

	Plant population (plants ha^{-1})				
NPS (kg^{-1})	**500,000**	**571,429**	**666,667**	**800,000**	**Mean**
0	1760^{g}	1800^{g}	2217de	2499^{c}	2069
50	1976^{fg}	2171^{ef}	2490^{c}	3024^{b}	2415.25
100	2142^{ef}	2210^{ed}	2507^{c}	3519^{a}	2594.5
150	2355^{cde}	2439^{cd}	2530^{c}	3539^{a}	2715.75
200	2436^{cd}	2512^{c}	2589^{c}	3575^{a}	2778
Mean	2133.80	2226.40	2466.60	3231.20	
LSD(0.05)	Population	NPS	Population* NPS		
	94.30	105.40	210.80		
CV (%)	5.10				

Where: LSD: Least significant difference, CV: coefficient of variation, Values followed by the different letter(s) within the column is not significantly different at 0.05 probability level

The highest seed yield per hectare (1,371kg) was recorded at higher plant population (800,000 plants ha^{-1}) with 200kg NPS ha^{-1}, which was statistically at par with 150 and 100 kg NPS ha^{-1} with 800,000 plants ha^{-1}, while the lowest seed yield per hectare (646 kg) was recorded at lower plant population (500,000 plants ha^{-1}) with control treatment (0kg NPS ha^{-1}) which was statistically at par with 571,429 and 666,667 plants ha^{-1} with 50 kg NPS ha^{-1}(Table 4). Similarly Kaysha *et al*. [17] recorded the maximum seed yield (1,244.7 kg ha^{-1}) at highest plant population and highest rate of NPS kg ha^{-1} and the minimum seed yield (655.7) at lowest plant population and nil rate of NPS kg ha^{-1}. This result was supported by Habtamu *et al*. [19] who reported that plant population and fertilizer rate increased seed yield per hectare. The reason for increased seed yield might be due to net crop assimilation rate and more number of plants harvested per unit areas. This might be due to higher stand count under higher plant population and adequate supply of nutrients added from the applied higher NPS fertilizer rate. In agreement with the results, Baza [15] reported significant interaction effect of blended NPS fertilizer rates and plant population on seed yield of pulses.

4.8 Straw Yield (kg ha^{-1})

The analysis of variance indicated that NPS fertilizer rates and plant population as well as their interactions had highly significant effect (P<0.001) on straw yield of mung bean (Table 5).

The highest straw yield per hectare (3,575 kg ha^{-1}) was obtained at highest plant population (800,000 plants ha^{-1}) from the plots with the highest NPS fertilizer rate (200kg ha^{-1}),which was statistically at par with 800,000 plants ha^{-1};received 100 and 150 kg ha^{-1}NPS fertilizer rate, while the lowest straw yield per hectare(1,760 kg ha^{-1}) was obtained at lowest plant population (500,000 plants ha^{-1}) from the plots with control NPS fertilizer application, which was statistically at par with

Table 6. Correlation coefficient among parameters of Phenological, Growth, Yield, and Yield Components of mungbean

Parameters	90%DM	TNPP	PH	NBPP	PPP	SPP	HSW	SC	AGBY	SY	HI	StY
90%DM	-											
TNPP	0.42***	-										
PH	0.12 ns	0.19 ns	-									
NBPP	0.46***	0.15 ns	0.28*	-								
PPP	0.51***	0.35**	0.25**	0.40**	-							
SPP	0.41**	0.35***	0.34**	0.38**	0.14 ns	-						
HSW	0.40**	0.47***	0.38*	0.5***	0.48***	0.71***	-					
SC	-0.16 ns	0.06 ns	0.25 ns	-0.06 ns	-0.16 ns	-0.01 ns	0.10 ns	-				
AGBY	0.11 ns	0.26*	0.45***	0.21 ns	0.17 ns	0.26*	0.48***	0.84***	-			
SY	0.35***	0.43***	0.54***	0.43***	0.42***	0.58***	0.75***	0.50***	0.84***	-		
HI	0.49***	0.44***	0.36**	0.50***	0.53***	0.72***	0.73***	-0.24 ns	0.17 ns	0.67***	-	
StY	-0.02 ns	0.14 ns	0.36**	0.07 ns	0.02 ns	0.06 ns	0.29*	0.92***	0.96***	0.67***	0.10ns	-

Where, DPM: Days to 90% physiological maturity, TNPP: Total nodules per plant ,PH: Plant height (cm), NBPP: Number of branch per plant (number), PPP: Pod per plant (number), SPP: Seed per pod (number), SC: stand count per hectare, HGW: Hundred Grain weight (gm),AGB: Above ground biomass (kg ha^{-1}), SY: seed yield (kg ha^{-1}), StY: straw yield (kg ha^{-1}) and HI: Harvest index (%)

Table 7. Partial budget analysis of the effect of plant population and NPS fertilizer rates on mung bean,

NPS (kg ha^{-1})	Plant population (plants ha^{-1})	seed rate (kg ha^{-1})	seed cost (Birr ha^{-1})	NPS cost (Birr ha^{-1})	fertilizer application cost (Birr ha^{-1})	seed sowing cost	straw yield (kg ha^{-1})	Adjusted straw yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Adjusted Grain yield (kg ha^{-1})	Gross/ Return (Birr ha-1)	TVC (Birr ha^{-1})	Net benefit (Birr ha^{-1})	MRR (%)
0	500,000	25	1125	0	0	750	1760	1584	646	581	26424	1875	24549	
0	571,429	26	1170	0	0	780	1866	1679	658	592	27047	1950	25097	730.40
0	666,667	28	1260	0	0	840	2217	1995	686	617	28687	2100	26587	993.20
0	800,000	30	1350	0	0	900	2499	2249	730	657	30778	2250	28528	1294.40
50	500,000	25	1125	782	100	750	1976	1778	741	667	30233	2757	27476 DDD	D
50	571,429	26	1170	782	100	780	2237	2013	800	720	32827	2832	29995	251.96
50	666,667	28	1260	782	100	840	2557	2301	905	815	37183	2982	34201	2988.80
50	800,000	30	1350	782	100	900	3024	2722	972	875	40435	3132	37303	2436.20
100	500,000	25	1125	1564	200	750	2208	1987	980	882	39254	3639	35615	D
100	571,429	26	1170	1564	200	780	2343	2109	996	896	40073	3714	36359	D
100	666,667	28	1260	1564	200	840	2773	2496	1126	1013	45527	3864	41663	595.66
100	800,000	30	1350	1564	200	900	3552	3197	1325	1193	54094	4014	50080	5610.80
150	500,000	25	1125	2346	300	750	2355	2120	1263	1137	49707	4521	45186	D
150	571,429	26	1170	2346	300	780	2573	2316	1283	1155	50819	4596	46223	D
150	666,667	28	1260	2346	300	840	2723	2451	1299	1169	51665	4746	46919	D
150	800,000	30	1350	2346	300	900	3579	3221	1348	1213	54970	4896	50074	D
200	500,000	25	1125	3128	400	750	2303	2073	1330	1197	52025	5403	46622	D
200	571,429	26	1170	3128	400	780	2579	2321	1335	1202	52702	5478	47224	D
200	666,667	28	1260	3128	400	840	2802	2522	1341	1207	53320	5628	47692	D
200	800,000	30	1350	3128	400	900	3572	3215	1371	1234	55786	5778	50008	D

Where MRR (%): Marginal Rate of Return; Fertilizer application cost =200 Birr/100kg ha^{-1}; NPS cost =15.64 Birr kg^{-1}; mung bean seed cost=45/kg; seed sowing cost =30 Birr/1kg; mung bean grain local selling price = 40 Birr kg^{-1}; straw local selling price = 2 Birr kg^{-1}; TVC: total variable cost; D: Dominated treatment

571,429 plants ha^{-1} from the plots with control NPS fertilizer application (0kg NPS fertilizer ha^{-1}) (Table 5). This might be due to improved growth under higher plant population due to better utilization of light and adequate supply of nutrients added from the applied NPS fertilizer. Similarly Shanko *et al*., [3] reported that the highest straw yield at higher plant population and the lowest straw yield at the lowest plant population.

4.9 Correlation Analysis

There was a significant (P ≤ 0.05, P≤ 0.01 and P≤ 0.001) and positive correlation between phenological and growth parameters, nodulation, seed yield, and yield components of mung bean (Table 6). seed yield was significantly and positively correlated with days to 90% physiological maturity (r=0.35**),total number of nodules (r=0.43**), plant height (r=0.54**), branches (r=0.43**), number of pod per plant (r=0.42*), number of seed per pod (r=0.58***), hundred seed weight (r=0.75***) above ground dry biomass yield(r=0.50***), stand count(r=0.84***), harvest index (r=0.67***) and straw yield (r=0.67***) (Table 6). The observation of positive correlation between seed yield and above traits implies NPS fertilizer application and optimum plant population via these traits could resulted in seed yield improvement. Similarly, Habtamu *et al*. [19] reported that there was a positive and significant correlation between parameters phenology, nodulation, growth, yield, and yield components of mung bean.

4.10 Economic Analysis

Economic Analysis was undertaken with different plant population and seed fertilizer rate treatments to determine the highest net benefit with acceptable marginal rate of return. The application of 100kg ha^{-1} NPS fertilizer with 800,000 plant populations ha^{-1} produced the highest net benefit (50080 ETB) with acceptable marginal rate of return (5610.80%), while the lowest net benefit (24549 ETB) was recorded from application of 0 $kgha^{-1}$NPS fertilizer with 500000 plants ha^{-1}(Table 7). This implies that the profitability of mung bean production is partly related to the right rate of fertilizer usage and right plant population and the cost incurred for these inputs. When the mung bean grower invests one birr for mung bean production, they could get 56.11 ETB as marginal rate of return. This result agreed with Abayneh [16] who concluded that the optimum plant population for mung bean 800000 plants per hectare obtained through the configuration of 25 and 5 cm between rows and plants within the row, respectively; and Kaysha *et al*. [17] who concluded that 100 kg ha^{-1} NPS fertilizer for mung bean production.

5. CONCLUSIONS

Almost all parameters such as days for 50% flowering, 90% physiological maturity, number of total nodules, number of effective nodules per plant, nodule fresh and dry weight, number of leaves per plant, number of branches per plant, tap root length, number of pods per plant, 100-seed weight and harvest index improved with higher rates of NPS fertilizer and lesser plant population. However, plant height, stand count, above-ground biomass, straw, and seed yields were increased with higher rates of NPS fertilizer rate and plant population. The highest number of pods per plant (4.79), seed per pod (10.78g), 100-seed weight (3.73), and harvest index (32.98%) were recorded under 200 kg ha^{-1} NPS fertilizer rate. Similarly the highest stand count per hectare (780,667 plants ha^{-1}), above-ground biomass (4,947kg ha^{-1}), straw yield per hectare (3,575 kg ha^{-1}) and seed yield ha^{-1} (1,371kg ha^{-1}) were recorded at higher plant population (800,000 plants ha^{-1}) with 200kg NPS ha^{-1}. Moreover application of 100$kgha^{-1}$ NPS fertilizer with 800,000 plant population ha^{-1}producedstatistically par seed yield (1325 kg ha^{-1}),while 200$kgha^{-1}$ NPS fertilizer and 800000 plants ha^{-1}recorded the highest net benefit of (50080 ETB) and marginal rate of return of (5610.80%) which was economically feasible for mung bean production in the study area.

In order to enhance mung bean production, soil amendment or fertilizer application can be recommended to compensate soil nutrient deficiency especially N, P, and S. Based on this study the combined application 100kgha-1 NPS fertilizer rate with 800000 plantsha-1produced 1325 kg ha-1 seed yield with highest net benefit of (50080 ETB) and marginal rate of return of 5610.8%. Hence, the combined application of 100kg ha-1NPS fertilizer with 800000 plants ha-1 can be recommended for the study area and similar agro-ecoloies. However, the current study was carried out only in one location for one cropping season, hence further studies over several seasons and locations are needed to have a conclusive recommendation for wide range of agro-ecologes for mung bean production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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