Asian Journal of Research in Crop Science

6(4): 28-39, 2021; Article no.AJRCS.72655
ISSN: 2581-7167

Effect of Plant Population and NPS Fertilizer Rates on Yield and Yield Components of Mung Bean (*Vigna radiata L. Wilczek*) in Bako, Western Ethiopia

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Authors' contributions

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

Article Information

DOI: 10.9734/AJRCS/2021/v6i430124
Editor(s):
(1) Dr. Moaed Al Meselmani, The University of Sheffield, England.
Reviewers:
(1) Anne anderson , Utah State University, USA.
(2) Emilio Olivares-Sáenz, Universidad Autónoma de Nuevo León, México.
Complete Peer review History: https://www.sdiarticle4.com/review-history/72655

Original Research Article

Received 10 June 2021
Accepted 17 August 2021
Published 21 August 2021

ABSTRACT

Mung bean (*Vigna radiata* L.) is a pulse crop with multiple uses and it was introduced recently in the study area. 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 optimum plant population and NPS fertilizer rates for mung bean borda varaity in Bako, Western Ethiopia. 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. The 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 (4.74g), seeds per pod (10.26g), 100-seed weight (3.61g), and harvest index (31.16%) were observed under minimum plant population (500,000 plants ha^{-1}). Moreover, the highest days for 50% flowering (49.08 days), 90% physiological maturity (64.5 days), effective nodules per plant (2.28),nodule fresh weight (0.33gm), nodule dry weight (0.141g $plant^{-1}$),plant height (11.10cm), number of leaves per plant (8.80),

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number of branches per plant (3.11), tap root length (8.99cm), number of pods per plant (4.79), seeds per pod (10.78g), 100-seed weight (3.73) and harvest index (32.98%) were observed under 200 kg ha^{-1} NPS fertilizer. The 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 (kg ha^{-1}). However, higher plant population (800,000 plants ha^{-1}) at the rate of 100 kg NPS ha^{-1}fertilizer produced 1,325 kg ha^{-1}seed yield which was the highest net benefit (50,080 ETB) 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-ecologes. 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*) also known as green gram is one of the most important pulse crop grown in different tropical and sub-tropical parts of the world [1]. Mung bean is a recently introduced pulse crop in Ethiopia. It is produced in North Shewa, Harerge, Illubabor, Gamo Gofa, Tigray and Gondar and exported [2]. It covers 41,633.20 hectares area and produces 514, 22.741 tons with average productivity of 1.235ton ha^{-1} [3].

Production of mung bean is influenced by improper plant population and fertilizer rates [4]. Very limited information is available regarding optimum plant population and fertilizer rates of mung bean in Bako, Western Ethiopia [5].

Despite holding such great promise in economic value, nutrition value and fertilizer uses, the production is relatively low in Ethiopia [6] and particularly in the study area, due to poor managements in plant population and NPS fertilizer rate [5].Therefore this study is planned to assess the effect of plant population and NPS fertilizer rates on growth, yield, and yield components of Mung bean. The objcives of the experiment was 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 in the study area.

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 [7].

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} area. Spacing between plots and blocks were 0.6 m and 1.5m, respectively and the 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.

2.1 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 from 10 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 to 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, [8]. This analysis was performed in order to evaluate the economic feasibility of the treatments at the minimum rate of return 50 to 100% [8]. Seed and straw yields of Mung bean from experimental plots were adjusted down ward by 10% 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 100 kg ha^{-1}), NPS fertilizer cost (15.64 ETB kg^{-1}), Mung bean seed cost (45 ETB kg^{-1}), and seed sowing cost (30 ETB kg^{-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.

3. RESULTS AND DISCUSSION

3.1 Physico-Chemical Properties of the Soils of Experimental Site

The results of soil analysis of the experimental field showed that the soil textural class was sand clay loam with a particle size distribution of 65.2% sand, 15.2% silt, and 25.5% clay (Table 1). According to rating done by Benton [7], the chemical reaction of the experimental soil was under strongly acidic category with a pH of 4.94. Organic carbon, organic matter, total Nitrogen, available Phosphorus, available Sulfur, CEC, Exchangeable Ca , and Exchangeable Mg of the experimental soil were 1.3%, 2.24%, 0.08%, 9.6 mg kg^{-1}, 11.74 mg kg^{-1}, 23 meq/100 g,10.6 meq/100 g, and 7.7 meq/100 g, respectively (Table 1).The value of organic matter and organic carbon content of the soil were under low category according to rating done by Tekalign et al. [9]. According to rating done by EthioSIS [10], the available Phosphorus and total Nitrogen were low category and the available Sulfur was also in low category. The values of CEC was medium, exchangeable Ca, and exchangeable Mg of the experimental soil were high category [11]. Generally the soil analysis result indicated that the area is nutrient deficient especially N, P, and S to support the potential crop production. This mght be associated with poor farm management practices and continuous cropping with little or no fertilizers input which resulted in decline in soil fertility of the area.

3.2 Days to 50% Emergence

The analysis of variance indicated that both main effects of plant population and NPS fertilizer rates as well as their interactions had no significant effect ($P \leq 0.05$) on days to 50% emergence (Table 1).

This might be due to the favorable environment for seed germination and seedling emergence. Viable seeds use their own stored food in their endosperm initially for germination and emergence when they get sufficient moisture and air. This result corroborates with Woubshet et al. [12] who reported that seeds depend mostly on stored food than on external nutrients for germination and emergence.

Table 1. Soil physico-chemical properties of the experimental field before sowing

Soil characteristics	Values	Rating /Category	References
		A. Soil texture	
Sand (%)	65.3		
Silt (%)	15.2		
Clay (%)	25.5		
Textural class		Sand Clay loam loam	Hazelton and Murphy(2007) (2007)
		B. Chemical analysis	
Soil pH	4.94	Very strongly acdic acidcacidic	Benton [7]
Organic carbon (%)	1.3	Low	Tekalign et al. [9]
Organic matter	2.24	Low	Tekalign et al. [9]
Total N (%)	0.08	Very low	Ethiosis [10]
Available P (mg kg^{-1})	9.6	Low	Ethiosis [10]
Available S (mg kg^{-1})	11.74	Medium	Ethiosis [10]
CEC (meq/100g soil)	23	Medium	FAO [11]
Exchangeable Ca(meq/100g)	10.6	High	FAO [11]
Exchangeable Mg (meq/100g) soil)	7.7	High	FAO [11]

3.3 Days to 50% Flowering and Days to 90% Physiological Maturity

The analysis of variance indicated that NPS fertilizer rates had significant effect ($P \leq 0.05$) on days to 50% flowering and 90% physiological maturity, however the main effects of plant population and main factors interactions had no significant effect ($P \leq 0.05$) on days to 50% flowering and 90% physiological maturity (Table 2).

The result indicated that days to flower and maturity were prolonged in response to the increased levels of NPS fertilizer rate. The longest days for 50% flowering (49.08 days) and 90% physiological maturity (64.5 days) were recorded under 200 kg NPS fertilizer rate ha^{-1}, while the shortest days for 50% flowering (45.58) and days for 90% physiological maturity (60.33) were recorded from control treatment (0 kg NPS fertilizer ha^{-1}) (1). The increased in days to flowering and maturity with the increase NPS fertilizers rates could be due to less competition as a result of high availability of growth resources that promote luxurious growth and prolonged flowering and maturity. Moreover, it could be due to N fertilization increased as the result of increased NPS rate which might have contribution for the vegetative growth of plants. This result was agreed with Nuru, [13] who observed that days to flower and maturity were prolonged in response to the increased rates of NPS. It is also in line with the findings of Wondimu et al. [14] who reported that increasing fertilizer rate from 0 kg to 200kg P_2O_5 ha^{-1} proportionately increased the time required to attain 50% flower and 90% physiological maturity.

3.4 Number of Total Nodules per Plant

The analysis of variance indicated that the NPS fertilizer rates had significant effect ($P \leq 0.5$) on number of total nodules per plant, while the main factor plant population and their interaction had no significant effect ($P \leq 0.5$) on number of total nodules per plant (Table 3).

As NPS fertilizer rates increased, number of total nodules per plant was increased. The highest number of total nodules per plant (2.53) was recorded from 200kg NPS fertilizer rate ha^{-1}, which was statistically at par with 50, 100, and 150 kg NPS fertilizer ha^{-1}, while the lowest number of total nodules (2.25) was recorded from control treatment (0 kg NPS fertilizer ha^{-1}) (Table 3). This might be due to the fact that phosphorus enhances the root and microbial activities in the root zone of the plant and in turn increases the absorption and fixation of nutrient, and ultimately increases the number of nodules per plant. This study was in line with Nuru [13], who reported that the highest numbers of total nodule from the application of high rate NPS ha^{-1} (150 kg NPS ha^{-1}) and the lowest numbers of total nodules from the control (0 kg NPS ha^{-1}). Similarly, Murat [15] reported that application of nitrogen in the range of 22 to 33 kg of Nitrogen ha^{-1} enhanced both nodulation and seed yield.

Table 2. Main effects of plant population and NPS fertilizer rates on phenological parameters of mung bean

Treatments	Days to 50% Flowering	Days to 90% Maturity
Plant population ha^{-1}		
500,000	48.27	63.80
571,429	48.13	63.00
666,667	47.27	62.07
800,000	46.40	61.13
Mean	47.52	62.50
LSD(0.05)	1.92	2.63
NPS (kg ha^{-1})		
0	45.58^{b}	60.33^{b}
50	46.83^{ab}	61.42^{ab}
100	47.67^{ab}	62.67^{ab}
150	48.42^{a}	63.58^{a}
200	49.08^{a}	64.50^{a}
Mean	47.52	62.50
LSD(0.05)	2.14	2.93
CV%	5.5	5.7

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

3.5 Number of Effective Nodules per Plant

The main effect of NPS fertilizer rates had highly significant ($P \leq 0.001$) on number of effective nodules per plant, whereas plant population and main factors interactions had non-significant effect ($P \leq 0.05$) on number of effective nodules per plant (Table 3).

The number of effective nodules per plant increased from 1.20 to 2.28 as NPS fertilizer rates increased from 0 kg to 200 kgha^{-1} (Table 3). The highest number of effective nodules per plant (2.28) was recorded at 200 kg NPS ha^{-1}, which was statistically similar with 150kg NPS ha^{-1}. This might be due to starter nitrogen supplemented in NPS form. It also might be due to sulfur which involved in the formation of nitrogenous enzyme known to promote nitrogen fixation in legumes and phosphorus which play an important role to stimulate biological activities like nodulation and nitrogen fixation. This result was in conformity with the results of Nebret [16], who reported that highest number of effective nodules (73.3 per plant) was obtained from application of 60 kgha^{-1} sulfur. Similarly, Murat et al. [15] reported that application of nitrogen in the range of 22 to 33 kgha^{-1} enhanced nodulation.

3.6 Number of Ineffective Nodules per Plant

The analysis of variance indicated that the main factor NPS fertilizer rates had highly significant effect ($P \leq 0.001$) on number of ineffective nodules per plant, whereas the main factor plant population and the main factors interactions did not affect significantly ($P \leq 0.05$) (Table 3).

The highest number of ineffective nodules per plant (1.05) was recorded from 0 kg NPS fertilizer rate ha^{-1}, while the lowest number of ineffective nodules per plant (0.25) was recorded from 200 kgha^{-1} NPS fertilizer rate which was statistically at par with 100 and 150 kg NPS ha^{-1} fertilizer rates (Table 3). The decreased in ineffective number of nodules as NPS fertilizer rates increased might be due to availability of phosphorus and sulfur fertilizer that stimulates nodule formation through increase the biological activity, which might be in turn decreased ineffective nodule and increased effective nodules per plant. This result agreed with Nuru, [13] who reported the highest ineffective nodule from control than other NPS fertilizer rates.

3.7 Nodule Fresh Weight

The analysis of variance indicated that the main factor NPS fertilizer rates had highly significant effect ($P \leq 0.01$) on nodule fresh weight, while the main factor plant population and the interactions had no significant effect ($P \leq 0.05$) (Table 4).

Under application of higher NPS fertilizer rate (200 kgha^{-1}), the maximum nodule fresh weight (0.33g plant^{-1}) was recorded which was statstically at parity with 100 and 150 kg NPS ha^{-}

^{1},while under control (0 kg NPS ha^{-1}) the lowest nodule fresh weight (0.25g plant^{-1}) recorded (Table 4).This might be due to adequate availability of N, P, and S, nutrients which might have facilitated the production of more nodule number, which might in turn, have contributed for higher weight of total nodule fresh weight. Moreover, it could be due to the growth elements present in NPS, which favored rapid cell division and multiplication. Nuru [13] also reported the increment of nodule dry and fresh weight due to increased N, P, and S availability.

3.8 Nodule Dry Weight

The nodule dry weight per plant of Mung bean was significantly affected by the main effect of plant population ($P \le 0.01$) and NPS fertilizer rate ($P \le 0.001$), while their interactions was non-significant (Table 4).

With increasing plant population from 500,000 to 800,000 plants ha^{-1} there were progressive decrease in nodule dry weight per plant. Thus, the highest number of nodule dry weight per plant (0.14 g plant^{-1}) was recorded at the lowest plant population (500,000 plants ha^{-1}) which was statistically similar with 571,429 plants ha^{-1} (0.13 g plant^{-1}), while the lowest (0.11 g plant^{-1}) was recorded at the highest plant population (800,000 plants ha^{-1}) (Table 4). This might be due to wider space between the plants resulted in decreased inter plant competition that in turn lead to increased plant capacity for utilizing the environmental inputs in building great amount of metabolites to be used in developing nodule. Similarly Shanko et al. [17], observed increased nodule dry weight with decreased plant population. The maximum nodule dry weight (0.141 g plant^{-1}) was recorded at higher NPS fertilizer rate (200 kg ha^{-1}), while the minimum nodule dry weight (0.110g plant^{-1}) recorded under control (0kg NPS ha^{-1}) treatment (Table 4). This might be due to the phosphorus which promotes the development of extensive root systems and good nodule development. Similarly, Arebu [18] observed the highest nodule dry weight (0.27 g plant^{-1}) from 46kg P_2O_5 ha^{-1} and the lowest (0.08 g plant^{-1}) from control. The reduction of nodule dry weight with the increased of phosphorus deficiency could be due to the limited growth and development as well as dry matter accumulation by the plant. Similarly Melkamu, [19] reported that an increased in sulfur fertilizer rate amplify fresh and dry nodule weights plant^{-1}.

3.9 Number of Leaves per Plant

The analysis of variance indicated that the main factor NPS fertilizer rates had significant effect ($P<0.05$) on number of leaves, while the main factor plant population and the main factor interactions were non-significant effect $P<0.05$) (Table 5).

Table 3. Main effects of plant population and NPS fertilizer rates on nodule parameters of mung bean

Treatments	Effective nodule plant^{-1}	Ineffective nodule plant^{-1}	Total nodule plant^{-1}
Plant population ha^{-1}			
500,000	2.00	0.52	2.52
571,429	1.94	0.56	2.50
666,667	1.90	0.59	2.49
800,000	1.84	0.60	2.44
Mean	1.91	0.57	2.48
LSD(0.05)	0.15	0.10	0.21
NPS (kgha^{-1})			
0	1.20^{d}	1.05^{a}	2.25^{b}
50	1.60^{c}	0.73^{b}	2.33^{ab}
100	2.05^{b}	0.34^{c}	2.39^{a}
150	2.16^{ab}	0.27^{c}	2.43^{a}
200	2.28^{a}	0.25^{c}	2.53^{a}
Mean	1.90	0.57	2.46
LSD(0.05)	0.20	0.10	0.20
CV (%)	10.4	22.1	11.7

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

Table 4. Main effects of plant population and NPS fertilizer rates on nodule fresh and dry weight

Treatments	Nodule fresh weight plant^{-1} (g)	Nodule dry weight plant^{-1}(g)
Plant population ha^{-1}		
500,000	0.29	0.14^{a}
571,429	0.28	0.13^{ab}
666,667	0.27	0.12^{b}
800,000	0.26	0.11^{b}
Mean	0.27	0.13
LSD(0.05)	0.02	0.01
NPS (kgha^{-1})		
0	0.25^{c}	0.110^{c}
50	0.26^{bc}	0.120^{bc}
100	0.27^{ab}	0.130^{ab}
150	0.29^{ab}	0.134^{a}
200	0.3^{a}	0.141^{a}
Mean	0.27	0.13
LSD(0.05)	0.03	0.01
CV%	11.9	12.7

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

The highest number of leaves per plant (8.8) was produced from higher amount of NPS fertilizer (200 kg ha^{-1}), while the lowest number of leaves per plant (7.45) were produced under control treatment (0kgha^{-1}) treatment (Table 5). This could be due to increased levels of nitrogen, phosphorus and sulfur fertilization, which promoted the vegetative growth of the plant including the number of leaves per plant. This finding agreed with Habtamu et al. [20] who observed the highest number of leaves per plant from 69/69 P_2O_5/ha Kg/ha and the lowest number of leaves per plant from control. Singh et al. [21] also reported that growth characters such as branches per plant, leaves per plant, and other attributes of Mung beans were significantly affected by different levels of phosphorus.

3.10 Plant Height (cm)

The analysis of variance indicated that the main factor NPS fertilizer rates had highly significant effect (P<0.01) on plant height, while the main factor plant population and the main factor interaction were non-significant effect (P>0.05) (Table 5).

The maximum plant height (11.10 cm) was recorded at higher NPS fertilizer (200 kg ha^{-1}), which was statistically similar with 100 and 150 kg NPS ha^{-1} while the minimum plant height (8.99 cm) was recorded under control (0 kg NPS ha^{-1}) treatment (Table 5). The increase of plant height with the increment of the rates of NPS fertilizer rates might be due to nitrogen, phosphorus, and sulfur nutrients are involved in vital plant functions and contribute to enhanced growth in the height of the crop. Moreover, phosphorus also plays a pivotal role in early root proliferation that might increase the nutrient uptake of the plants which resulted in increased vegetative growth. This result was in conformity with the finding of Nuru [13], who reported increase in plant height of Mung bean, in response to NPS fertilizer application (0 kg N ha^{-1} and 150 kg P_2O_5 ha^{-1}).

3.11 Number of Branches per Plant

The number of branches per plant was highly significantly (P<0.01) affected by the main effect of NPS fertilizer rates, while main effect of plant population and their interaction were non-significant (P<0.05) (Table 5).

The maximum number of branches per plant (3.11) was recorded under application of 200 kg NPS rate ha^{-1} which was statistically at parity with 100 and 150 kg NPS ha^{-1}, while minimum the number of branches per plant (2.6) was recorded under control treatment (0 kg NPS ha^{-1}) (Table 5). Kaysha et al. [4] also indicated that increased NPS rates; increased branches due to adequate availability of N, P, and S nutrients which facilitated the production of more branches and canopy development. Similarly Nuru [13] observed the highest number of branches per plant from 150 kg NPS ha^{-1} fertilizer rate and the lowest number of branches per plant (3.59) observed from control (0 kg NPS ha^{-1}).

Table 5. Main effects of plant population and NPS fertilizer rates on growth parameters of mung bean

Treatments	Leaf number per plant	Plant height (cm)	Branch number	Tap root length per plant
Plant population ha^{-1}				
500,000	8.69	10.37	3.00	8.77
571,429	8.38	10.26	2.92	8.67
666,667	8.08	10.03	2.83	8.41
800,000	7.89	9.91	2.77	8.09
Mean	8.26	10.14	2.88	8.49
LSD(0.05)	0.922	1.21	0.28	0.69
NPS (kg ha^{-1})				
0	7.45^{b}	8.99^{c}	2.60^{b}	7.78^{b}
50	8.01^{ab}	9.45^{bc}	2.70^{b}	8.40^{ab}
100	8.35^{ab}	10.38^{abc}	2.91^{ab}	8.47^{ab}
150	8.68^{a}	10.81^{ab}	3.08^{a}	8.79^{a}
200	8.80^{a}	11.10^{a}	3.11^{a}	8.99^{a}
Mean	8.26	10.15	2.88	8.49
LSD(0.05)	1.03	1.35	0.32	0.78
CV (%)	15.10	16.10	13.3	11.10

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

3.12 Tap Root Length (cm)

The analysis of variance indicated that the main effect of NPS fertilizer rates was significantly ($P<0.05$) affected the tap root length of Mung bean, while the main effect of plant population and their interaction were non-significantly ($P<0.05$) on tap root length (Table 5).

The longest tap root (8.99 cm) was recorded under application of higher NPS fertilizer rate (200 kg ha^{-1}) which was statistically similar with 50, 100 and 150 kg NPS ha^{-1}, while the shortest tap root length (7.78 cm) was recorded under control (0 kg NPS ha^{-1}) treatment (Table 5). This could be due to the fact that availability of Phosphorus and Nitrogen attributed for better environment for growth and development. The increased availability of phosphorus to plant might have enhanced early root growth and cell multiplication leading to more absorption of other nutrients from deeper layers of soil and ultimately resulted in improved plant growth in terms of plant height, root length, number of nodules, and number of branches. This result was supported by Geletu and Mekonnen [22] who stated that an increase in the rate of application of fertilizer linearly increased the mean root length in Mung bean cultivar.

Table 6. 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 7. 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

3.13 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 5).

The highest seed yield per hectare (1,371 kg) was recorded at higher plant population (800,000 plants ha^{-1}) with 200 kg 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 (0 kg NPS ha^{-1}) which was statistically at par with 571,429 and 666,667 plants ha^{-1} with 50 kg NPS ha^{-1} (Table 5). Similarly Kaysha et al. [4] 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. [20] 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 [23] reported significant interaction effect of blended NPS fertilizer rates and plant population on seed yield of pulses.

3.14 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 7).

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 (200 kg 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 571,429 plants ha^{-1} from the plots with control NPS fertilizer application (0kg NPS fertilizer ha^{-1}) (Table 7). 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., [17] reported that the highest straw yield at higher plant population and the lowest straw yield at the lowest plant population.

4. CONCLUSION

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 100kgha^{-1} NPS fertilizer with 800,000 plant population ha^{-1} porduced statistically par seed yield (1325 kg ha^{-1}), while 200 kg ha^{-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 plants ha-1 produced 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.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle4.com/review-history/72655