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Growth and Seed Yield Response of Fenugreek (*Trigonella foenum graecum* L.) to NPSB Fertilizer Rate and Row Spacing in Leka Dulecha District, Western Ethiopia

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Abstract

The field experiment was conducted during 2023/24 cropping season at Leka Dulecha district, East Wollaga, Ethiopia. The treatments consist of four NPSB fertilizer rates (0, 25, 50 and 75 kg ha⁻¹) and three row spacing (20, 30 and 40 cm) that gave 12 treatments with three replication. The treatment was laid out in a randomized complete block design in factorial arrangement with three replications. Analysis of variance revealed that days to 50% flowering, days to 90% physiological maturity, plant height, number of secondary branches plant⁻¹, number of nodules plant⁻¹, nodule dry weight plant⁻¹, number of pods plant⁻¹, number of seeds pod⁻¹, and biological yield were significantly affected by the main effect of NPSB fertilizer. The number of primary branches plant⁻¹, thousand seed weight, and grain yield of fenugreek were significantly affected by the interaction effects of NPSB rates and row spacing. The 30 cm row spaced and applied with 50 kg NPSB ha⁻¹ resulted in the highest number of primary branches plant⁻¹ (5.8) and the highest thousand seed weight (18.47g). The highest grain yield (1160.67 Kg ha⁻¹) was achieved from 50 kg NPSB ha⁻¹ with 40 cm row spacing. The highest marginal rates of return (13564) were recorded from treatment combination 25 kg NPSB ha⁻¹ with 20 cm row spacing. Based on economic analysis growing local landrace along with 25 kg ha⁻¹ rate of NPSB fertilizer with 20 cm row spacing recommended.

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Blended fertilizer, local landrace, Inter row spacing, Nodule, Seed quality.

Introduction

Fenugreek (*Trigonella foenum-graecum* L.) is an annual herbaceous legume crop that is self-pollinating and believed to be native to the Mediterranean region but is now widely cultivated in India and other parts of the World (Achaya *et al.*, 2006). It is originated in the countries bordering on the eastern shores of the Mediterranean and is widely cultivated in India, China, Egypt, Ethiopia, Morocco, Ukraine, Greece, and Turkey (Petropoulos, 2002). India is the leading producer in the world, and Ethiopia, Egypt, Algeria, and Morocco are major producers in Africa. Among other Asian countries, Iran, Israel, China, and Pakistan also have high levels of

production. Ethiopia is recognized as the original homeland of *Trigonella foenum-graecum* subspecies Mediterranean, ecotype Abyssinian, with its distribution extending to neighboring countries (Feysal, 2006).

A study reported the presence of fenugreek genetic variability as well as its production and distribution in Ethiopia as being nearly similar to those of other cool-season food legumes (DZARC, 2004).

Fenugreek occupies 42,344.28 hectare, with productions and productivity of 507,472.35 quintals and 11.98 quintals ha⁻¹, respectively (CSA, 2023). In Ethiopia, Oromia Regional State shared the second-most

production with a productivity of 13.02 quintal ha⁻¹, next to Amhara Region, which is 14.55 quintal ha⁻¹ (CSA, 2023).

The regional average productivity of fenugreek was low as compared to its potential yield (CSA, 2023). Moreover, the productivity of fenugreek in East Wollega is very low as compared with other parts of Ethiopia, which is 6.90 quintal ha⁻¹ (CSA, 2023). Production of Fenugreek is constrained by several factors that reduce yield and quality. Among those factors, poor soil fertility (N, P, S and B deficiencies) and fertilizer management as well as inappropriate plant row spacing have considerable practical importance (Gutema *et al.*, 2021).

A crop can perform at its best only when the spread of the foliage on the ground surface is done in such a manner that the utilization of natural resources is maximized. An increase in plant density results in increased competition among the plants for growth requirement factors such as adequate space for growth and development of shoots and roots, light, nutrients, and moisture, and as a result, individual plants show less growth and development. But, despite the reduced growth and development of individual plants, the total biological yield per unit area increases due to the increased number of plants per unit area (Peiman *et al.*, 2011). The maximum seed yields were obtained from the closer row spacing treatments as observed by (Gill *et al.*, 2005; Singh *et al.*, 2005).

Majority of farmers in East Wollega and Leka Dulecha district sow fenugreek without defined row spacing i.e., broadcasting method and without fertilizer application. The lack of information on Blended NPSB fertilizer application rates coupled with optimum row spacing are major hindrances to the growth and yield of Fenugreek in East Wollaga area.

Hence, to alleviate the existing gap, the current research was designed to address the following objective: To determine the optimum rate of Blended NPSB fertilizer and row spacing for better yield and quality of fenugreek in Leka Dulecha District, East Wollaga, Western part of Ethiopia. Research on Blended NPSB fertilizer practices for the fenugreek crop is given little attention in Ethiopia. Scientifically supported information regarding nutrient management and row spacing was limited. The growth and yield of fenugreek in East Wollaga area are hindered by a lack of information on Blended NPSB fertilizer application rates and optimal row spacing. Therefore, the objective this study was to evaluate the

effect of Blended NPSB fertilizer rate and row spacing on growth, yield components, and protein content of fenugreek.

Materials and Methods

Description of the Study Area

The experiment was conducted in Leka Dulecha District, East Wollega Zone, Oromia National Regional State, Western Ethiopia, during the main cropping season of 2023/24 under rain-fed conditions. Leka Dulecha is located 375 km away from Addis Ababa to Western and 18 Km away from the zonal capital town, Nekemt. The altitudinal variation ranges from 1140 – 3752 m.a.s.l. and is divided into three major agro-ecological zones locally identified as Dega, Woynadega, and Kola, i.e., 9% Dega, 47% Woyna dega, and 44% Kola, which are comparable to say highland, midland, and lowland, respectively. It has a mean annual rainfall of 1244 mm, a mean maximum temperature of 29 °C, a mean minimum temperature of 12 °C, and a mean relative humidity of 60.6% (LDAO, 2022). The altitude of experimental field was 1962 m.a.s.l. The study area obtains rainfall from April to November which accounts for 70% of the annual rainfall. The soils are red, brown, and vertisol. The experimental site Badhoo Kebele is located about 10 km west of Leka Dulecha district and is geographically located at 8°51'03.5 N latitude and 36°28'43E longitude.

Soil Sampling and Analysis

Soil Sampling

Using a cylindrical auger a representative soil sample was taken at a depth of 0–20 cm randomly in a zigzag pattern from entire experimental field before planting and mixed to form one composite sample. Working samples were obtained from submitted bulk samples and analyzed for organic C, total N, available S, CEC, soil pH, available P, available B, and soil texture. The analysis of sample soil conducted at Oromia Agricultural Research Center, Nekemt Soil Testing Laboratory.

Soil organic carbon content was analyzed by Walkley-Black chromic acid wet oxidation method. In this method, oxidisable matter in the soil is oxidized by 1 NK₂Cr₂O₇ solution. The reaction is assisted by the heat generated when two volume of H₂SO₄ are mixed with one volume of the dichrome. The total N content in the soil was analyzed by Kjeldahl method. The method involves the digestion of soil samples with concentrated

sulfuric acid, which converts organic nitrogen to ammonium sulfate. The ammonium sulfate is then neutralized with sodium hydroxide and distilled with magnesium oxide to release ammonia gas. The ammonia gas is then absorbed in a known amount of acid and the amount of nitrogen present is determined by titration. Available S analyzed by oxidation method. In this method, the sample was heated in an oxygen atmosphere to form SO₂, which was then measured by an infrared detector.

CEC determined by ammonium acetate method. The method involves mixing the soil with an excess of 1 N ammonium acetate solution, which resulted in an exchange of the ammonium cations for exchangeable cations present in the soil. The excess ammonium was removed, and the amount of exchangeable ammonium was determined. Soil pH measured by adding deionized water in a soil: water ratio of 1:2. Available P measured by Olsen method. The method was based on the extraction of phosphate from the soil by 0.5 N sodium bicarbonate solution adjusted to pH 8.5. The orthophosphate ion reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a complex. Available B measured by Hot water extraction in 0.01 M CaCl₂ solution, and soil texture estimated by Bouyoucos Hydrometer method. The method involves the use of a hydrometer to measure the density of soil particles in a suspension. The soil sample first treated with a dispersing agent such as sodium hexa meta phosphate (calgon) for 15 to 20 hours before being dispersed for only 2 minutes.

Soil Physico-chemical Properties of the Experimental Site before Sowing

Composite soil (0-20 cm depth) samples that were taken prior to sowing were examined for soil's physico-chemical characteristics (Table 1). As a result, the sand component dominates the soil texture at the experimental site. According to the distribution of particle sizes, the soil is made up of 60% sand, 24% silt, and 16% clay and its texture class is sandy loam.

According to Cottenie rating the soil has a medium amount of available P (10.64 ppm), which means that additional P fertilizer sources must be applied for crop growth and yield (Cottenie, 1980). The soil analysis result revealed that the soil had a low OC content (1.14%), which indicates that it has a limited capacity to supply nutrients, particularly S, to plants through mineralization, given that organic matter is the major

source of S (about 95%) (Landon, 1991). Lewis' rating indicates that the level of available S (19.24 ppm) is extremely low, indicating the need for the application of N and S fertilizer (Lewis, 1999). According to Tekalign (1991) assessments the pH of the experimental site is neutral (6.70). The pH range for the majority of crops is between 6.5 and 7.5 (FAO, 2008).

Experimental Materials

The study was conducted using a fenugreek (local landrace), the commercial variety which was conserved at local farmer, in 2023. The landrace is adaptable to this agro ecology. The altitudinal requirement ranges 1700–2600 m.a.s.l. and an average annual rainfall of 700–1200 mm. The local landrace was selected based on yield, disease resistance, farmer acceptance, and adaptability to the agro-ecology of the study area. The average seed yields are 800–1450 and 900–1800 kg ha⁻¹ on farmer fields and research fields, respectively (Gutema *et al.*, 2021). The used seed rate was different based on row spacing. 20 cm 7.75 Kg ha⁻¹, 30 cm 6.2 Kg ha⁻¹ and 4.46 Kg ha⁻¹ rate for 40 cm row spacing was used. And the seed was obtained from farmer.

Experimental Treatments and Design

The national recommended amount of fertilizer for fenugreek (local landrace) production in the country is 50 kg ha⁻¹, and the spacing between rows was 20 to 30 cm. The treatments consisted of two factors: Four blended NPSB fertilizer rates (0, 25, 50, and 75 kg ha⁻¹) and three row spacing (20 cm, 30 cm, and 40 cm) which was combined factorial to give 12 treatments. The experiment was laid out in a randomized complete block design (RCBD) in factorial arrangement with three replications. The size of the unit plot was 1.5 m by 2.4 m (3.6 m²). The total number of treatments was 12 (4 levels of NPSB x 3 levels of row spacing). The spacing between plants was 10 cm. Based on the inter row space, each plot had a different number of rows, i.e., 20 cm between rows, 12 rows plot⁻¹, 30 cm had 8 rows plot⁻¹, and 40 cm had 6 rows plot⁻¹. Excluding the border rows net area of 1.2m x 1m was used for yield estimation.

Experimental Procedure and Field Management

The experimental field was ploughed, disked and harrowed using oxen. And down implements and pulverized to a fine tilth by hand digging. Blocking and the required number of rows were marked in each plot according to the row spacing proposed and rows were

made to plant the seeds. The plots were leveled manually. The seeds were planted as per the interspacing treatments maintained 10 cm. The spacing between plots and blocks was 0.5m and 0.75m, respectively.

The seeds were hand sown, and application of NPSB fertilizer was done at the time of sowing for all treatments depending on the rate that was determined except for control. All agronomic practices like weeding and tillering were applied uniformly to all the experimental units as per the farmers' practices.

Six, four and three middle rows of one meter length, for 20, 30, and 40 cm row spacing, respectively, were used for data collection and one row plot⁻¹ was for destructive sampling.

Border rows of each plot were left out to protect border effects. At full maturation stage, in order to estimate seed yield, biological yield and 1000-seed weight, a final harvesting from a net area of 1.2 m x 1 m in the middle of each plot was done.

The crop was harvested manually in each plot separately and tied into bundles. The bundles were left in the field for drying until constant weight. The sun-dried bundles were weighed by scale to determine total biomass plot⁻¹ (at the given area) and converted into kg ha⁻¹. The bundles were manually threshed to record seed yield (tone ha⁻¹). Seeds were additionally dried until 10% of moisture and subsequently yield was determined. The spacing between plots and blocks was 0.5m and 0.75m, respectively. The seeds were hand sown, and application of NPSB fertilizer was done at the time of sowing for all treatments depending on the rate that was determined except for control.

Data Collection

Crop phenology and Growth parameter

Days to 50% flowering: recorded by counting the number of days taken from the date of sowing until 50% of the plants flower in each plot.

Days to 90 % Physiological maturity: recorded by counting the number of days from sowing until 90% of the plants in each plot were physiologically mature, which explained by the yellowing of straw.

Plant height: The height of six randomly chosen plants from middle rows was measured from the ground to the

tip of the plant. The average was worked out and expressed as plant height in cm.

Number of primary and secondary branches plant⁻¹: The number of primary and secondary branches plant⁻¹ was counted from six randomly chosen plants from middle rows at the plant had fully matured in each plot, and the mean values were calculated and recorded.

Nodule number and nodule dry weight plant⁻¹: The number of nodules plant⁻¹ was recorded from destructive row at the mid flowering stage from six randomly selected plants. At the mid flowering stage six randomly selected plants were uprooted from destructive row and the soil adhering was washed from it with tap water to clean the roots and nodules from the top and lateral root parts were removed separately and spread on a sieve for some time until all the water had drained from the surface of the nodules. Then, the nodule number plant⁻¹ was counted and averaged plant⁻¹. After drying, the collected nodules from selected six weighed and averaged to record the dry weight of nodules plant⁻¹ in gram.

Yield and yield component

Pod length: Six randomly chosen plants pod (six pod plants⁻¹) from middle rows at physiological maturity were measured from the base to the tip of the pod and their mean was recorded.

Number of pods plant⁻¹: The pods of six randomly chosen plants pod (five pod plant⁻¹) from middle rows at the time of physiological maturity were counted and average was recorded as pods plant⁻¹.

Number of seeds pod⁻¹: Seed of six randomly chosen plants pod (five pod plants⁻¹) from middle rows were counted and averaged to compute seed number pod⁻¹.

Thousand seed weight: 1000 seeds were counted in samples drawn from the finally cleared seed and weighed.

Biological yield (t ha⁻¹): The weight of thoroughly sun dried harvested produce of each net plot was recorded separately before threshing as biological yield, then it was converted into t ha⁻¹.

Grain Yield (kg ha⁻¹): This was measured by harvesting the seed yield from the net plot area (1.2 m²). Before threshing manually, the harvested produce was sun-dried for seven days. Then the weight was converted to kg ha⁻¹.

Harvest Index (%): This was calculated by dividing grain yield per net plot area by total above-ground dry biomass yield per net plot area and multiplied by 100.

$$\text{Harvest index (\%)} = \frac{\text{Grain Yield}}{\text{Biological Field}} \times 100$$

Quality parameter

Protein Content: A chemical tests were carried out at Jimma University Post harvest department laboratory. The powdered of fenugreek seeds to their aqueous extract and alcoholic extract are subjected to the tests to identify their crude protein content (Kokate *et al.*, 2009) by using standard procedures to preliminary phytochemical screening, as preparation of extracts by weighting ten grams of fenugreek seeds powder are macerated in 300 cm³ of boiled and cooled distilled water and ten grams from seed powder to plant are macerated in 100 cm³ of ethanol 97% at room temperature, then extracts are collected after 24 hr (Harborne, 1985). Special statements were then made on prepared extracts. Total protein in the sample was determined by kjeldahl method used stem distillation, in which the ammonia released from digested protein was titrated against standard HCl (AOAC, 2003).

Data analysis

The collected data were subjected to analysis of variance (ANOVA) using GLM procedure of SAS version 9.4 and after the significance determined test of mean separation was done using Duncan's Multiple Range Test (DMRT) at 5 % probability level using SAS.

Results and Discussion

Crop phenology and Growth parameter

Days to 50% flowering: The number of days needed to reach 50% flowering increased significantly from 44 days to 48 days as the rate of blended NPSB fertilizer increased from zero to 75 kg ha⁻¹, with no significant difference between the control and 25 kg NPSB ha⁻¹, and also between 50 and 75 kg ha⁻¹ kg ha⁻¹. The significant difference was observed between unfertilized and 75 kg ha⁻¹ (Table 2).

The longest days (47) in response to row spacing were recorded at 40 cm which is, at par with 30 cm row spacing (46). The narrow spacing (20 cm) flowered

sooner (45 days), statistically not different from 30 cm (46) (Table 2). Accordingly, the longest days to 50% flowering (40.83 cm) were recorded at row spacing of 50 cm, while the shortest days to 50% flowering (36.05) were recorded at 20 cm row spacing (Table 2).

Days to 90% Physiological maturity: The time needed to reach physiological maturity was reduced as the rate of blended NPSB fertilizer decreased from 75 to zero kg ha⁻¹. The control and 50 kg ha⁻¹, between control and 75 kg ha⁻¹, between 50 kg ha⁻¹ and 75 kg ha⁻¹ and between 25 kg ha⁻¹ and 75 kg ha⁻¹, while there is no difference between control and 25 kg ha⁻¹ (Table 2).

With regard to row spacing, 20 cm early matured (93) which were statistically on with 30 cm (95). The lowest seed pod⁻¹ (13.75) was recorded from 20-cm row spacing. Whereas, plot adjusted with 40 cm row spacing late matured (97days) which are statistically different from 20 cm. (Table 2).

Plant height: The fertilizer rate of 75 kg NPSB ha⁻¹ recorded the tallest plant height (36.9 cm) with no significant variation among the different rates of application. The smallest plant height (29.5 cm) was observed at zero NPSB (Table 2).

Plant height increased as plant row spacing increased. Here, it should be noted that there was less competition between plants for resources such as nutrients, water, sunlight, and space. This might be because more nutrients were made available through the use of chemical fertilizers and more bacteria were able to fix N.

Number of primary and secondary branch's plant⁻¹: The interaction of 100 kg ha⁻¹ and 30 cm row spacing produced the highest primary branch plant⁻¹ (5.8), which was statistically equivalent to the value of (5.5) obtained by 75 kg ha⁻¹ and 40 cm row spacing, while the interaction of 0 kg NPSB ha⁻¹ and 20 cm row spacing produced the lowest primary branch plant⁻¹ (4.13) (Table 3).

Secondary branch plant⁻¹

The number of secondary branches plant⁻¹ increased significantly from 3.477 to 5.3 as the rate of blended NPSB fertilizer increased from zero to 75 kg ha⁻¹. Additionally, the number of secondary branches plant⁻¹ increased significantly from 4.3 to 5.3 as the row spacing increased from 20 cm to 40 cm with no significant difference between 30 and 40 cm row spacing (Table 2).

Nodule number and nodule dry weight plant⁻¹: Nodule number and nodule dry weight plant⁻¹ were significantly ($p < 0.001$) affected due to NPSB application, while neither spacing nor their interaction showed a significant effect. A higher number of nodules plant⁻¹ (24.22) was obtained from 75 kg ha⁻¹ of NPSB. The lowest nodule number (10.44) was obtained from control. The number of nodule showed successive improvements as the NPSB level increased from control to 75 kg ha⁻¹ (Table 2). Nodule dry weight increased along with nodule number when the rate of NPSB fertilizer increased from 0 to 75 Kg ha⁻¹. The control had the lowest nodule dry weight plant⁻¹ (Table 2).

Yield and Yield Component

Pod length: The maximum pod length (7.25) was recorded at 75 kg NPSB ha⁻¹, with non-significant difference among the rates except control. Pod length rises from 6.54 to 7.25 when NPSB rates rises from 0 to 75 kg ha⁻¹ (Table 5).

Number of pods plant⁻¹: The highest (25.2) pod number plant⁻¹ was produced at 75 kg NPSB fertilizer ha⁻¹ application rates which is statistically at par with the number of pods produced plant⁻¹ at other application rates except the control. At the control, significantly smallest pod number (17.95) was recorded (Table 5). The effects of applying 25, 50, and 75 kg of NPSB ha⁻¹ on pod length were comparable.

Number of seeds pod⁻¹: The addition of 25 kg of NPSB ha⁻¹ produced the largest number of seeds pod⁻¹ (16.02), followed by 50 kg of NPSB ha⁻¹ (14.81), and the lowest number (13.28) was produced from the control treatment, which was statistically equivalent to 25 kg of NPSB ha⁻¹ (Table 5). As NPSB was applied more frequently, there was more seeds pod⁻¹.

Thousand seed weight: The 50 kg NPSB kg ha⁻¹ with 30 cm spacing treatment combination resulted in the greater thousand seed weight (18.47 g) which is statistically similar with the thousand seed weight obtained from all NPSB applied in compilation of 40 cm row spacing, and plots received the maximum rates of NPSB regardless of row spacing. While the treatment combination of 50 kg ha⁻¹ with 20 cm spacing produced the lowest thousand seed weight (15.37 g) (Table 4).

Biological yield: The highest biological yield (5.7 ton ha⁻¹) was obtained with 75 kg of NPSB applied ha⁻¹, and it was statistically comparable to 50 kg of NPSB applied

ha⁻¹ (5.6 ton ha⁻¹). Whereas the lowest biological yield (3.63 ton ha⁻¹) was recorded with no NPSB treatment (Table 5).

The biological yield was highest (5.27) at 20 cm row spacing and lowest (4.63) at 40 cm row spacing (Table 5). **Grain Yield:** In comparison to 25 kg of NPSB ha⁻¹ with 20 cm row spacing, the combined effect 50 kg of NPSB ha⁻¹ with 40 cm spacing, the highest seed yield (1160.67 kg ha⁻¹) was recorded from application of 50 kg NPSB ha⁻¹ and 40 cm row spacing which is statistically at par with grain yield obtained from the combination of application of same rate of NPSB and 30 cm row spacing and 25 kg NPSB ha⁻¹ and 20 cm row spacing. While the lowest yield (567 kg ha⁻¹) was obtained from 20 cm row spacing with no NPSB fertilizer application (Table 6). Sufficient N containing fertilizer supply with optimum row spacing may increase photosynthesis and photosynthetic translocation, which increase yield by promoting flowering and fruiting.

Harvest Index (%): The lowest harvest index (16.15) was recorded for 75 kg ha⁻¹ fertilizer application. While the highest harvest index (18.77) was recorded for unfertilized plot which was statistically at par with 25 kg ha⁻¹ NPSB fertilizer and 75 kg ha⁻¹ NPSB fertilizer. Significant different observed between unfertilized and 75 kg ha⁻¹ NPSB fertilizer (Table 5). With regard to row spacing the lowest harvest index (16.27) was recorded for 20 cm row spacing, while the highest harvest index (19.81) was recorded for 40 cm row spacing, which was statistically at par with 30 cm row spacing (17.97). Significant different observed between 20 cm and 40 cm row spacing only (Table 5).

Quality parameter

Protein Content: The difference in seed protein content between NPSB application and row spacing was found to be non-significant. Similarly, no significant variation was realized due to the interactions of the two factors (Table 5).

Crop phenology and Growth parameter

Days to 50% flowering: The main effects of blended NPSB fertilizer rates and row spacing had a significant ($P < 0.05$) effect on the number of days it took for a plant to reach 50% flowering, but their interaction had no significant effect. This may be because P in NPSB fertilizer promotes the reproductive phase through accelerated flowering. According to this finding, NPSB

application to fenugreek significantly increased the number of days to flowering which may be due to its supply of P, also as reported by Gutema *et al.*, (2021). The result is also contrary with Sarbessa *et al.*, (2019), who reported that earlier flowering occurred when fenugreek was applied with 26 kg P₂O₅ ha⁻¹ as compared to control and 9 kg ha⁻¹. The fact that P promotes the production of cytokinins may be the cause of the earlier flowering at higher rates (Horgan and Wareing, 1980).

Additionally, by accelerating physiological activity, it increases the supply of photoassimilates for flower formation (Marschner, 1995). P has a significant effect on plant growth and metabolism (Abel, 2002), because it is a component of DNA and RNA, which regulate cell division. However, the current finding, contradicts Sheoran *et al.*, (2000) observation that P had no discernible effect on floral initiation.

Significant difference was observed between 20 cm and 40 cm row spacing. Similar to these findings, Asaye *et al.*, (2018) reported that row spacing had a significant effect on the days to 50% flowering of mung beans. Accordingly, the longest days to 50% flowering (40.83 cm) were recorded at row spacing of 50 cm, while the shortest days to 50% flowering (36.05) were recorded at 20 cm row spacing (Table 2).

Furthermore, this result might be because wider row spacing had a better light interception as compared to the narrow row spacing, resulting in more number of days to flowering of fenugreek. The longest days to flowering with a wider inter- and intra- row spacing might be due to the fact that more nutritional area available in the wider row spacing which might have caused the crop to flower later than the narrower spacing (Asaye *et al.*, 2018).

Days to 90% Physiological maturity: The main effect of blended NPSB fertilizer rates and row spacing had a significant ($p < 0.05$) effect on days to 90% maturity. However, their interaction had no significant effect on days to 90% maturity. The supplied nutrient to fenugreek plants' promoted timely growth and thus seed set, seed filling which in turn increased days to physiological maturity as compared to the control treatment. The results are contrary with those of Serbesa *et al.*, (2019); Gutema *et al.*, (2001), who found that the application rate of NPS fertilizer affected the number of days it took for fenugreek to reach 90% physiological maturity, with 200 kg NPS ha⁻¹ applied producing the shortest time to maturity (114 days). It is possible that an increase in

fertilizer rate could lead to an increase in vegetative growth and a decrease in reproductive growth. This could result in a shorter time to reach physiological maturity.

With regard to row spacing, 20 cm early matured (93) which were statistically on with 30 cm (95). The lowest seed pod⁻¹ (13.75) was recorded from 20-cm row spacing. Whereas, plot adjusted with 40 cm row spacing late matured (97days) which are statistically different from 20 cm. (Table 2). The findings concurred with those of Hasesh *et al.*, (2000); Gowda *et al.*, (2006) who reported beneficial effects of row spacing applications on yield characteristics of fenugreek.

Plant height: According to the analysis of variance, the main effects of blended NPSB fertilizer rates had a significant ($p < 0.05$) effect on plant height; however their interaction had no significant effect on plant height. Blended NPSB fertilizer application regardless of its rate of application caused significant increase in plant height compared to control treatment. As N in the blended NPSB is a necessary component of chlorophyll, this may have aided in better N absorption and utilization, which in turn produced more photosynthates and increased plant height due to higher photosynthesis. It might also be brought on by P cumulative effect on cell division and a healthy diet (Zafar *et al.*, 2003).

The absence of significant variation among the rates of fertilizer application on fenugreek plant height could be attributed to several factors. One possible reason is the uniform nutrient requirements of fenugreek plants across different fertilizer application rates.

Fenugreek plants may not exhibit a significant response to varying nutrient levels, resulting in similar plant heights regardless of the fertilizer rate. Another reason could be that fenugreek plants are not sensitive to changes in nutrient availability. They might have a high tolerance for nutrient deficiencies or excesses, which could explain the lack of variation in plant height (AAFC, 2022).

This result is supported by the findings of Gutema *et al.*, (2019), who found that varieties and NPS fertilizer had main effects on plant height. Accordingly, the local landrace with the application of 200 kg NPS ha⁻¹ had the highest plant height (53.67 cm), which was statistically no different to the same variety with the application of 75 kg NPS ha⁻¹. The variety Ebisa with no NPS fertilization had the lowest plant height (38.27 cm).

There is no significant difference between any of the treatments when it comes to row spacing (Table 2). This outcome was consistent with the early research of Mohamed *et al.*, (1990), who reported that increasing row spacing had no effect on the plant height of fenugreek. Plant height increased as plant row spacing increased. Here, it should be noted that there was less competition between plants for resources such as nutrients, water, sunlight, and space. This might be because more nutrients were made available through the use of chemical fertilizers and more bacteria were able to fix N.

Number of primary and secondary branch's plant⁻¹: Primary branch plant⁻¹ was significantly ($p < 0.05$) affected by the main effects of blended NPSB fertilizer and row spacing's as well as their interaction. It's possible that N in the NPSB fertilizer, which is responsible for crop branching, is what causes an increase in the number of branches with an increase in the NPSB rate. Additionally, P₂O₅ role in cell division activity, which is crucial for increasing plant height, branch count, and dry weight (Tesfaye *et al.*, 2007). Similar to this treatment combination of 80 kg N ha⁻¹ with 30 x 20 cm recorded maximum number of branches (7.37) as Anupama *et al.*, (2017) reported. This could be attributed to the enhanced availability of fertilizers at the appropriate row spacing which might have resulted in increased photosynthetic rate and accumulation of metabolites in plants.

Secondary branch plant⁻¹

The interaction between blended NPSB fertilizer and row spacing did not significantly affect the number of secondary branches plant⁻¹. While, the main effects of blended NPSB fertilizer rates and row spacing significantly ($p < 0.05$) affects number of secondary branch plant⁻¹. Similar to this result Dinesh *et al.*, (2016) reported that plots with row spacing of 25 cm and 30 cm showed the highest number of branches as compared to other spacing's, and row spacing of 5 cm showed the lowest number of branches. With wider row spacing, there were more branches. For the number of branches in fenugreek, similar findings were reported in earlier studies by Halesh *et al.*, (2000); Gowda *et al.*, (2006); Mohamed *et al.*, (1990). Wider row spacing allows more sunlight to reach the plants and reduces inter-plant competition for resources such as water and nutrients. This results in better growth and development of individual plants, which in turn leads to more branches per plant.

Nodule number and nodule dry weight plant⁻¹: Nodule number and nodule dry weight plant⁻¹ were significantly ($p < 0.001$) affected due to NPSB application, while neither spacing nor their interaction showed a significant effect. The number of nodule showed successive improvements as the NPSB level increased from control to 150 kg ha⁻¹ (Table 2). This might be related to the added P in NPSB stimulated nitrogenase activity in the roots, enhancing root nodulation and fostering a hospitable rhizosphere for the plant, which led to a rise in physiological growth indices.

This result was in line with the report of Serbessa *et al.*, (2019). Accordingly lowest nodule number was found in accession 28606 with no P treatment, whereas a greater nodule number was achieved with 26 kg ha⁻¹. The added P stimulated nitrogenase activity in the roots, enhancing root nodulation and fostering a hospitable rhizosphere for the plant, which led to a rise in physiological growth indices. It is, therefore, the addition of more amount of P enhances the nodule number. Additional supply of P promotes the initiation of more nodules, increasing the number of nodule primordials which is essential for the development and functioning of nodules. Similarly, Bashir stated P plays a vital role in expanding plant tip and root growth in legumes (Bashir *et al.*, 2011).

ANOVA of nodule dry weight revealed a significant ($p < 0.001$) effect of NPSB treatment. However, there were no significant differences due to row spacing and the interaction of NPSB and row spacing.

Nodule dry weight increased along with nodule number when the rate of NPSB fertilizer increased from 0 to 150 Kg ha⁻¹. The control had the lowest nodule dry weight plant⁻¹ (Table 2). Increasing the P treatment enhanced the number of root nodules and dry weight as reported by (Abbasi *et al.*, 2010).

Yield and Yield Component

Pod length: The effects of NPSB rates on pod length were observed significant ($P < 0.05$). However, the effects of row spacing and the interaction of row spacing and NPSB rates were non-significant. The longer pods may be a result of the soil's enhanced P availability, which allows the root to transmit more P to the sink and more photosynthates from sources to the sink (pod) than in the control plot. It is possible that the increased availability of nutrients from fertilizers may have contributed to the observed increase in pod length.

Table.1 Soil physiochemical properties of the experimental site before sowing fenugreek at Leka Dulecha district during 2023/24 cropping season

| Soil properties | Values | Ratings | References |
|-----------------------------|-------------|---------------|----------------------------|
| Physical properties | | | |
| Clay (%) | 16 | | |
| Silt (%) | 24 | | |
| Sand (%) | 60 | | |
| Texture class | Sandy Loam | | |
| Chemical Properties | | | |
| PH (1:2.5 H ₂ O) | 6.7 | Neutral | (Tekalign, 1991) |
| CEC (meq/100gm soil) | 31.99 | High | (Roy <i>et al.</i> , 2006) |
| Available P (ppm) | 11.02 | Medium | (Roy <i>et al.</i> , 2006) |
| Available S (ppm) | 22.3 | Very low | (Lewis, 1999) |
| Available B (ppm) | 0.87 | Low | (London, 1991) |
| Total N (%) | 0.16 | Medium | (Tekalign, 1991) |
| Organic carbon (%) | 3.08 | Medium | (Tekalign, 1991) |

Table.2 Main effects of NPSB and row spacing on days to 50% flowering, days to 90% physiological maturity, plant height, secondary branch plant⁻¹, number of nodule plant⁻¹ and nodule dry weight of fenugreek grown at Leka Dulecha district during 2023/24 cropping season

| Fertilizer | DF | DM | PH | SB | NNPP | NDWPP |
|----------------|------------|------------|-------------|-------------|------------|--------------|
| 0 | 44b | 91c | 29.5b | 3.4c | 10.4d | 17.4c |
| 25 | 46ba | 94bc | 32.8ba | 4.7b | 13.5c | 18.9c |
| 50 | 46ba | 98b | 35a | 4.9ba | 15.3b | 25.7b |
| 75 | 48a | 104a | 36.9a | 5.7a | 24.2a | 28.4a |
| Mean | 46 | 96.75 | 33.5 | 4.7 | 15.8 | 22.6 |
| MS | 19.6 | 170.6 | 90.8 | 7.8 | 314.5 | 250.8 |
| LSD | 2.26 | 5.4 | 4.25 | 0.87 | 1.37 | 2.33 |
| Spacing | | | | | | |
| 20 | 45b | 93b | 33.2a | 4.3b | 15.5a | 22.2a |
| 30 | 46a | 95ab | 34.4a | 4.5ba | 16.1a | 22.9a |
| 40 | 47ab | 97a | 32.9a | 5.3a | 16.1a | 22.7a |
| Mean | 46 | 95 | 33.5 | 4.73 | 15.8 | 22.6 |
| MS | 29.1 | 92.1 | 8.0 | 3.1 | 1.3 | 1.7 |
| LSD | 1.9 | 2.3 | NS | 0.75 | NS | NS |
| CV | 5.0 | 5.8 | 12.9 | 18.8 | 8.8 | 10.5 |

Means with the same letter(s) are not significantly different at 5% probability level.

Table.3 Interaction effects of blended NPSB fertilizer and row spacing on number of primary branch plant⁻¹ of fenugreek grown at Leka Dulecha district during 2023/24 cropping season

| Fertilizer Level | Spacing | | | Mean |
|------------------------|-------------------|--------------------|--------------------|-------------|
| | 20cm | 30cm | 40cm | |
| 0 kg ha ⁻¹ | 4.1 ^d | 4.8 ^{bcd} | 4.4 ^{cd} | 4.46 |
| 25 kg ha ⁻¹ | 4.6 ^{cd} | 4.5 ^{cd} | 4.8 ^{bcd} | 4.63 |
| 50 kg ha ⁻¹ | 4.9 ^{bc} | 5.8 ^a | 4.8 ^{bcd} | 5.17 |
| 75 kg ha ⁻¹ | 4.4 ^{cd} | 4.9 ^{bc} | 5.5 ^{ab} | 4.95 |
| Mean | 4.52 | 5 | 4.89 | 3.14 |
| LSD (5%) | 0.71 | | | |
| CV (%) | 8.76 | | | |

Means with the same letter(s) are not significantly different at 5% probability level

Table.4 Interaction effects of fertilizer and row spacing on thousand seed weight of fenugreek grown at Leka Dulecha district during 2023/24 cropping season

| Fertilizer Level | Spacing | | | Mean |
|-----------------------|------------------------|-----------------------|-----------------------|--------------|
| | 20cm | 30cm | 40cm | |
| 0kg ha ⁻¹ | 15.88 ^{def} | 15.83 ^{ef} | 16.14 ^{edef} | 17.27 |
| 25kg ha ⁻¹ | 16.72 ^{bcdef} | 16.2 ^{bcdef} | 17.46 ^{ab} | 16.79 |
| 50kg ha ⁻¹ | 15.37 ^f | 18.47 ^a | 17.56 ^{abc} | 16.84 |
| 75kg ha ⁻¹ | 17.2 ^{abcde} | 17.32 ^{abcd} | 17.69 ^{ab} | 16.46 |
| Mean | 16.62 | 16.83 | 17.07 | 16.84 |
| LSD (5%) | 1.49 | | | |
| CV (%) | 5.25 | | | |

Means with the same letter(s) are not significantly different at 5% probability level

Table.5 Main effects of NPSB fertilizer and row spacing on pod length, number of pod plant⁻¹, seed pod⁻¹, biological yield, harvest index and protein content of fenugreek grown at Leka Dulecha district during 2023/24

| Fertilizer | PL | NPPP | SPP | BY | HI | PC |
|-------------|-------------|--------------|-------------|-------------|--------------|---------------|
| 0 | 6.54b | 17.95b | 13.28c | 3.63c | 18.77a | 25.85a |
| 25 | 6.95ba | 22.77a | 13.95bc | 4.90b | 18.57a | 25.18a |
| 50 | 6.91ba | 23.01a | 14.81b | 5.60a | 18.55a | 26.69a |
| 75 | 7.25a | 25.2a | 16.02a | 5.70a | 16.15b | 25.21a |
| Mean | 6.9 | 22.23 | 14.51 | 4.95 | 18.01 | 25.73 |
| MS | 0.75 | 84 | 12.52 | 8.23 | 13.94 | 4.5 |
| LSD | 0.468 | 4.66 | 0.959 | 0.4404 | NS | NS |
| Row Spacing | | | | | | |
| 20 | 6.86a | 19.52a | 13.75b | 5.27a | 16.27b | 25.7a |
| 30 | 6.96a | 23.31a | 14.59a | 5.01ab | 17.96ab | 26.5a |
| 40 | 6.91a | 22.86ba | 15.21a | 4.63b | 19.81a | 24.9a |
| Mean | 6.917 | 22.23 | 14.51 | 4.81 | 18.51 | 25.7 |
| MS | 0.03 | 72.4 | 6.5 | 1.23 | 37.83 | 6.9 |
| LSD | NS | NS | 0.83 | 0.38 | 2.01 | NS |
| CV | 6.92 | 21.43 | 6.75 | 9.05 | 13.21 | 12.66 |

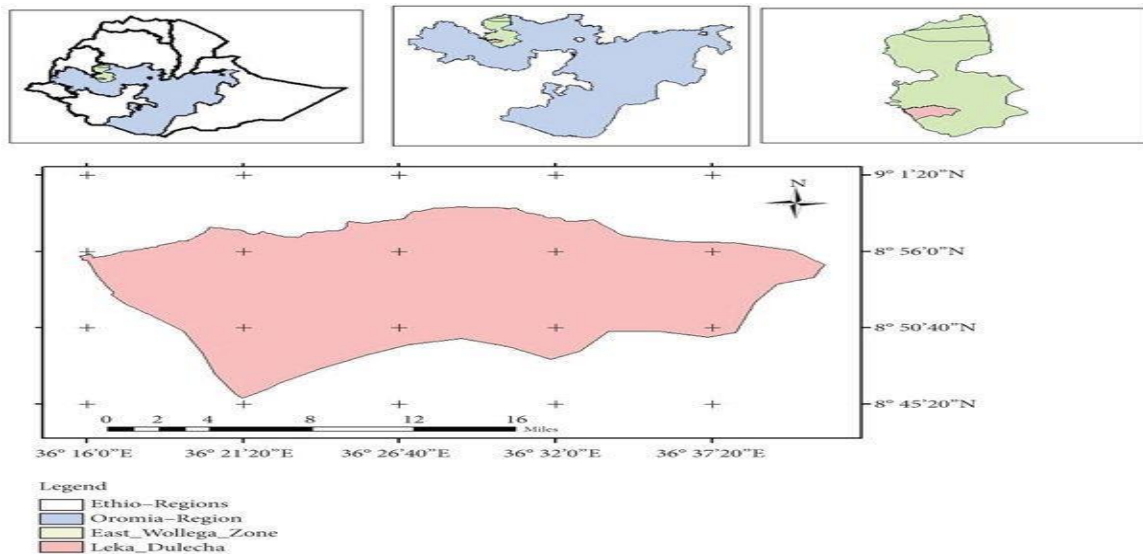
Means with the same letter(s) are not significantly different at 5% probability level

Table.6 Interaction effects of fertilizer and row spacing on grain yield of fenugreek grown at Leka Dulecha district during 2023/24

| Fertilizer Level | Spacing | | | Mean |
|-----------------------|----------------------|----------------------|----------------------|---------------|
| | 20cm | 30cm | 40cm | |
| 0kg ha ⁻¹ | 567.3 ^f | 759 ^{de} | 702.6 ^{ef} | 676.3 |
| 25kg ha ⁻¹ | 1016.4 ^{ab} | 879 ^{bcd} | 821 ^{cde} | 905.5 |
| 50kg ha ⁻¹ | 952.5 ^{bc} | 1013.1 ^{ab} | 1160.67 ^a | 1042.1 |
| 75kg ha ⁻¹ | 893 ^{bcd} | 890.7 ^{bcd} | 953.5 ^{bc} | 912.4 |
| Mean | 857.3 | 885.45 | 909.5 | 884.1 |
| LSD (5%) | 174.21 | | | |
| CV (%) | 11.63 | | | |

Means with the same letter(s) are not significantly different at 5% probability level

Figure.1 Map of study area



This result fit with Serbessa *et al.*, (2019) findings. In similar higher P rates than control treatments resulted in the maximum pod height as Khiriya and Singh, (2003) reported.

Number of pods plant⁻¹: Application of NPSB fertilizer had a significant ($p < 0.05$) effect on the number of pods produced plant⁻¹. However, row spacing and the interactions between row spacing and NPSB fertilizer rates did not show significant effects. The highest (25.2) pod number plant⁻¹ was produced at 150 kg NPSB fertilizer ha⁻¹ application rates which is statistically at par with the number of pods produced plant⁻¹ at other application rates except the control. At the control, significantly smallest pod number (17.95) was recorded (Table 5). The effects of applying 50, 100, and 150 kg of

NPSB ha⁻¹ on pod length were comparable. This may be a result of P role in cell division and feeding, which promotes balanced development and improved reproductive efficiency in plants.

It might also be attributed to the sufficient supply of N and P content of blended NPSB fertilizer applied, which may have aided in the growth of more primary and secondary branches and plant height, both of which may have contributed to the production of more total pods. P application levels above average resulted in a higher number of pods plant⁻¹ as Shweta *et al.*, (2014) reported. Fertilizing with P resulted in a notable increase in the number of lentil pods produced plant⁻¹ due to the cumulative effect of P on cell division and a healthy diet (Zafar *et al.*, 2003).

By increasing phosphate rates, fenugreek plants produced considerably more pods plant⁻¹ as Kumar *et al.*, (2000); Ramesh *et al.*, (2002) reported. The role of P in several enzymatic activities that boost blooming and pod formation may be the cause of the increased number of pods with an increased P rate (Nehara *et al.*, 2006).

On P deficient soils, legumes have consistently produced more grain on P source application because P also promotes the growth and retention of more pods plant⁻¹ (Chiezey, 2001).

Number of seeds pod⁻¹: The main effects of NPSB fertilizer rates and row spacing had a significant ($p < 0.001$) effect on number of seed pod⁻¹. However, due to the interaction effect of NPSB fertilizer rate and row spacing the result was non-significant. As NPSB was applied more frequently, there was more seeds pod⁻¹. The increase may be attributable to P, which helps legumes produce seeds that are more uniformly shaped, disease-resistant, have better floral development, and have higher seed quality (Kumar *et al.*, 2000).

The largest number of seeds pod⁻¹ at the highest NPSB rate may be due to the proportionately larger concentration of P nutrients assimilated in seeds, which serves as a reservoir of carbohydrates and contributes to the higher number of seeds pod⁻¹. This conclusion closely similar to the findings of Tunçtürk (2011), who found that the number of seeds pod⁻¹ dramatically increased as the P rates was increased.

The application of P rate considerably increased the number of seeds pod⁻¹ of faba beans, with the largest number of seeds pod⁻¹ (3.41) being obtained from faba beans with an application of 69 kg P₂O₅ ha⁻¹ (Ayele, 2016). With regard to row spacing, 40 cm produced the most seeds pod⁻¹ (15.21), followed by 30 cm (14.59), which was statistically equal. The lowest seed pod⁻¹ (13.75) was recorded from a 20- cm row spacing (Table 5). The findings concurred with those of Hasesh *et al.*, (2000); Gowda *et al.*, (2006) who reported beneficial effects of row spacing applications on yield characteristics of fenugreek.

Thousand seed weight: Thousand seed weight of fenugreek was significantly ($p < 0.05$) affected by main factors of blended NPSB rates and row spacing as well as their interaction. These findings suggested that optimal row spacing and balanced application of NPSB fertilizer increased the efficiency of the key nutrients, which increased seed weight and yield.

Biological yield: The results of ANOVA revealed that the main effects of NPSB application and row spacing had a significant ($P < 0.001$) effects on biological yield. However, the interaction of these two factors had no significant effect. The beneficial effect of P contains fertilizer on vigorous growth, bumper yield and better quality, guarantees timely and uniform maturity, enormous nodule and extensive root formation in legume crops may be the cause of the improvement of biological yield at applied P containing fertilizer over control. The rise in biological yield at the fertilizer's maximum rate may be a sign that the nutrients are working in concert to boost the plant's metabolism, chlorophyll production, and photosynthesis (Fageria, 2009).

Similarly Gutema *et al.*, (2021) reported, the biomass yield of 200 kg NPS ha⁻¹ was the highest (7160 kg ha⁻¹), and that it was statistically equal to that of 150 kg NPS ha⁻¹ (7037 kg ha⁻¹). On the other hand, no NPS application produced the lowest biomass (6006 kg ha⁻¹). This finding is consistent with Alemu (2009) who reported the highest fenugreek biomass yield (6508.9 kg ha⁻¹) from 26 kg P₂O₅ ha⁻¹ application. This results were in line with those of Yilmaz (2008), who noted that narbon vetch (*Vicia narbonensis* L.) had an 18.5% increase in above-ground biomass at harvest when P rates were raised to 75 kg P₂O₅ ha⁻¹. On the other hand, Rakesh *et al.*, (2012) reported that gradually increasing S rates increased mungbean biomass yield. The application of 40 kg P₂O₅ ha⁻¹ gave significantly higher biological yields, supported the findings Methal *et al.*, (2012).

Row spacing had a significant ($p < 0.01$) effect on biological yield. Individual plants exhibit less growth and development as a result of increased competition among the plants for growth-related factors like sufficient space for the growth and development of shoots and roots, light, nutrients, and moisture when grown under narrow row spacing. However, because there are more plants per unit area, the total biological yield per area increases even though individual plant growth and development are reduced (Peiman *et al.*, 2011).

Grain Yield: Blended NPSB application rates and the interaction between blended NPSB application rates and row spacing had a significant ($p < 0.05$), effect on grain yield on fenugreek. A crop's grain yield is determined by yield attributes like the number of pods plant⁻¹, the number of seeds pod⁻¹, and the weight of 1000 seeds. These attributes grow as a result of improved nutrient uptake and utilization, and they have a direct and

beneficial impact on the seed and biological yields of fenugreek. An increase in plant growth attributes and yield components led to an increase in seed yield (Dubey *et al.*, 2012).

Sufficient N containing fertilizer supply with optimum row spacing may increase photosynthesis and photosynthetic translocation, which increase yield by promoting flowering and fruiting. Increased nutrient uptake by the plants may have speed up a number of physiological processes, including growth and nutrient assimilation, which may have contributed to the yield increase with an increased by N containing fertilizer rate, such as a higher grain filling percentage and more seeds pod⁻¹ (Khiriya *et al.*, 2001). The current finding is line with that of Kurubetta *et al.*, (2018), who reported the interaction of row spacing 30 x 10 cm with fertilizer dose F1-50:50:0 kg NP₂O₅K₂O ha⁻¹ recorded significantly higher seed yield of 15.5 quintal ha⁻¹.

Harvest Index (%): The harvest index was significantly ($p < 0.01$) affected by the main effect of fertilizer and row spacing. However, the interaction between spacing and NPSB application had no significant effect on the fenugreek harvest index. Significant different observed between 20 cm and 40 cm row spacing only (Table 5). Narrower plant row spacing, the harvest index was reported to decrease as full radiation interception during seed formation is required for maximum seed yield, and conditions resulting in a high seasonal interception like higher plant density may not result in highest seed yield. This finding was in agreement with the report of Birhanu *et al.*, (2018).

In line with this result Mehta *et al.*, (2012) reported that harvest index was not significantly affected with P levels in fenugreek. However, contrary to the current result, Zafar *et al.*, (2003) reported that calculated values of harvest index showed an increasing trend in the harvest index values with application of P on lentil and minimum harvest index from the control plot. Similarly, Ali (1993) reported that inoculation and P application exhibited significant effect on harvest index of chick pea.

Quality parameter

Protein Content: The difference in seed protein content between NPSB application and row spacing was found to be non-significant. Similarly, no significant variation was realized due to the interactions of the two factors (Table 5). In agreement with this finding Ruvéyde *et al.*, (2011) reported that the protein content of fenugreek

seeds was not significantly affected by row spacing or P fertilizer rates. Also Garima (2019) reported that the protein content of fenugreek seed can be influenced by both genotype and phenotype.

Conclusion and Recommendations

Due to nutrient shortages, particularly N, P, S and B, most tropical soils, including those of Ethiopia, have a limited ability to produce high crop yields. Because of this, crop yields frequently fall short of their genetic potential. The productivity of fenugreek is below the global average because there are insufficient agronomic management practices, particularly in relation to nutrients and plant density. Providing well-balanced nutrients with ideal row spacing to meet the crop's nutrient needs is one solution to this problem. In order to evaluate the effect of NPSB fertilizer rates and row spacing on growth, yield components, and seed yield of fenugreek under various NPSB rates and row spacing, an experiment was carried out.

The findings of this study showed that, with the exception of seed protein content, the application of NPSB significantly influenced yield and yield components of fenugreek. Overall, the findings showed that the tested fenugreek growth and productivity were greatly improved by NPSB fertilizer and row spacing.

In general, this study showed that the yield and financial performance of fenugreek could be increased by applying NPSB fertilizer at the best rates and with the best row spacing.

The combination that produced the highest net benefit 50 kg NPSB ha⁻¹ with 20 cm row spacing was a promising one. Overall, the findings showed that growth, yield characteristics, and seed yield varied significantly depending on the amount of NPSB applied and the row spacing.

Based on economic analysis it could be suggested to use a 50 kg ha⁻¹ rate of NPSB fertilizer with 20 cm row spacing. Therefore, farmers growing fenugreek in the study area and areas with similar agro-ecology can be advised to use the local landrace along with 50 kg ha⁻¹ rate of NPSB fertilizer with 20 cm row spacing.

However, the study needs to be repeated in a different year and location in order to provide comprehensive recommendations in the study area and areas with similar agro-ecology.

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