



Optimization of NPS Fertilizer Rate and Row Spacing for Growth and Yield of Fenugreek (*Trigonella foenum-graecum* L.) at Wolaita Sodo, Southern Ethiopia

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ABSTRACT

Background: Fenugreek (*Trigonella foenum graecum* L.) is an important self-pollinated seed spice crop belonging to family Fabaceae. Fenugreek production and productivity in the study area is very low as compared to its potential yield mainly due to inappropriate application of fertilizer rates and plant spacing. Hence, field experiment was conducted in 2022 at Wolaita Sodo, Ethiopia. The objective of study was to investigate and determine optimum inter row spacing and NPS fertilizer for growth and yield of fenugreek.

Methods: Treatments consisted of four NPS fertilizer rates (0, 50, 100 and 150 kg ha⁻¹) and four inter-row spacing (10, 20, 30 and 40 cm) that gave a total of 16 treatments laid out in randomized complete block design (RCBD) with three replications.

Result: The ANOVA result indicated that the main effects of fertilizer rates, inter-row spacing and their interactions significantly ($p < 0.05$) affected most traits investigated. Accordingly, the highest number of pod (17.10) and seed yield per plant (13.70 g) were recorded by application of 150 kg ha⁻¹ NPS with 40 cm inter row spacing. The maximum total above ground biomass (3.46 t ha⁻¹) and seed yield (1.60 t ha⁻¹) were obtained by application of 150 kg ha⁻¹ NPS with 10 and 20 cm inter row spacing, respectively. Moreover, the economic analysis revealed that the highest net benefit (279,130 ETB ha⁻¹) with marginal rate of return of 2,976% was obtained by 150 kg NPS ha⁻¹ with 20 cm inter row spacing. Hence, 150 kg ha⁻¹ NPS with 20 cm inter row spacing could be recommended for production and productivity of fenugreek in Wolaita area.

Key words: Fenugreek, Fertilizer, Growth, Seed, Spacing, Yield.

INTRODUCTION

Fenugreek (*Trigonella foenum graecum* L.) is an important self-pollinated seed spice crop belonging to family Fabaceae (Suleiman *et al.*, 2008). Ethiopia is one of the countries in the world where fenugreek is most widely cultivated. Fenugreek is cultivated between altitudes of 1600 and 2300 m above sea level and some researchers reported presence of fenugreek genetic variability in Ethiopia (Million *et al.*, 2012). Out of the total cultivated land in Ethiopia, fenugreek occupies 42344.28 ha with production and productivity of 50747.255 tones and 1.2 tone ha⁻¹, respectively in 2020/2021. This low yield of fenugreek in Ethiopia is attributed to several production constraints, such as lack of high yielding improved varieties, lack of attention to improved agronomic practices including poor soil fertility management and improper plant spacing practiced among farmers.

The use of optimum fertilizer is one of the most important factors to increase crop yield per unit area; however, the response to the type of fertilizer, method and rate of application vary widely with location, climate and soil type (Marschner, 1995). Altering the soil nutrients and fertility status by providing a balanced and adequate dose of major nutrients like nitrogen, phosphorus and sulfur as per the crop requirement is one of the easiest ways to boost up the productivity of fenugreek (Mozumder *et al.*, 2003).

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Nitrogen is an important major nutrient element for plant. For legumes, it is more useful because it is the main component of amino acids as well as proteins. Adequate supply of nitrogen is essential for normal growth and yield (Mozumder *et al.*, 2003). Phosphorus is the most important yield-limiting elements that required by legume crops (Fageria *et al.*, 2010). In plant metabolism it plays an important role via cellular energy transfer and being key structural component of nucleic acids coenzymes and proteins (Blackshaw *et al.*, 2004). Sulfur is also an important nutrient for plant growth and its uptake by plants accounts 9 to 15% of nitrogen uptake. It has been reported that the

amount of nitrogen fixed by legumes increases with the treatment of sulfur and as a result of this, soil fertility improves (Mohammed, 2018).

On the other hand, plant population and arrangement of plants in a unit area greatly determine resource utilization such as light, nutrients and water; the rate and extent of vegetative growth and development of crops; and the seed cost. It also affects canopy development, plant architecture and distribution of pods (Gemechu and Solomon, 2021). Wider or too low spacing beyond the optimum can affect the yield of crops. The best way to get uniform plant stand is to plant in regularly spaced rows and at regular intervals within the row (Faisul *et al.*, 2013).

In study area, there was no information available on optimum inter row spacing of fenugreek with recommended rate of NPS fertilizer for optimization of growth and yield potential of the crop. Therefore, majority of the farmers use blanket traditional doses of fertilizer and some of the farmers do not use at all. Thus, the current research was conducted to address the existing problem with the following objectives:

- To investigate the growth and yield response of fenugreek to NPS fertilizer rates and inter row spacing at Wolaita Sodo, Southern Ethiopia.
- To determine economic optimum and cost effective NPS fertilizer rate with appropriate inter row spacing for fenugreek production in the study area.

MATERIALS AND METHODS

Description of experimental site

The experiment was conducted in 2022 cropping seasons at Woliata Sodo Agricultural Technical Vocational Education and Training College (ATVET) demonstration field in Wolaita Zone, Southern Ethiopia. The site is geographically located at 6°52'30"N latitude, 37°46'30"E longitude with an altitude of 1950 meters above sea level. The area has a bimodal rainfall distribution pattern with average annual rainfall of 1250 mm. The average minimum and maximum air temperature is 13.5°C and 23°C, respectively. The soil type was texturally classified as clay with pH of 5.1 that was strongly acidic. The map of study area is indicated on Fig 1.

Treatments and experimental design

Fenugreek *Challa* variety was used as a test crop. The NPS (19% N, 38% P₂O₅ and 7% S) was used as the sources of fertilizer. The treatments consisted of two factors: four NPS fertilizer rates (0, 50, 100 and 150 kg ha⁻¹) and four inter row spacing (10, 20, 30 and 40 cm) that gave (4 × 4) a total of 16 treatment combinations. The experiment was laid out in randomized complete block design (RCBD) with three replications. Plant spacing was 10 cm between plants and each plot had a gross area 2.88 m² with length 1.2 m and width 2.4 m. Based on the inter-row spacing, each plot had a different number of rows *i.e.*, 10 cm inter row had 24 rows per plot; 20 cm inter row had 12 rows per plot; 30 cm inter

row had 8 rows per plot; and 40 cm inter row had 6 rows per plot.

Data collection

Data collected for the study include days to 50% flowering, days to 80% maturity, number of branches per plants, number of pods per plant, pod length (cm), number of seeds per pod, single pod weight (g), seed yield per plant (g), thousand seed weight (g), seed yield per hectare (t ha⁻¹) and total above ground biomass (t ha⁻¹).

Data analysis

ANOVA

Data collected were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the General Linear Model (GLM) procedure of statistix 8 software. The means were compared using least significance difference (LSD) test at 5% level of significance.

Economic analysis

Economic analysis was conducted following methodology (CIMMYT, 1988). The seed yield of the fenugreek was used for partial budget analysis as described by (CIMMYT, 1988). For partial budget analysis of the treatment combinations, the fertilizer cost, the seed cost, the labor costs for seed application and harvesting, transportation costs were considered as the variable costs and all other costs were taken as constant for all treatments. For the calculation of net benefit, the market price of fenugreek seed during harvesting at Wolaita sodo market. The field price of 1kg of fenugreek seed yield at the time of harvesting was 225 Birr/kg based on the market price of seed at Wolaita Sodo town near experimental site. Price of NPS was 37.80 Birr/kg and the daily laborer expense was 100 Birr per men per day. The gross benefit was calculated by 10% adjusted seed yield (tone/ha) multiplied by field price.

RESULTS AND DISCUSSION

Effect of different fertilizer dose and plant spacing on growth and yield attributes

The analysis of variance revealed that the main effects of NPS fertilizer rates and inter row spacing highly significantly ($p \leq 0.05$) influenced all the tested traits. While, the interaction effects of NPS fertilizer rates and inter row spacing significantly ($p \leq 0.05$) affected majority of the tested parameters except, pod length, number of seeds per pod, single pod weight and thousand seed weight (Table 1).

Days to 50% flowering

Analysis of variance indicated that the main effect of NPS fertilizer rates, spacing and their interaction highly significantly ($p < 0.05$) influenced days to 50% flowering of fenugreek (Table 1). Days to 50% flowering of fenugreek determines the growth stage of the crop, in which the crop is transformed in to reproductive stage. The maximum period required to reach days to 50% flowering (46 days)

was recorded by combined application of 150 kg ha⁻¹ NPS fertilizer and 40 cm inter row spacing which was statistically similar with application of 150 kg ha⁻¹ NPS fertilizer and 30 cm between rows spacing. The shortest number of days to 50% flowering (36 days) was recorded by the control treatment with 10 cm spacing (Table 2). Days to flowering linearly increased with increasing NPS fertilizer rate and wider inter row spacing. This indicates the more supply of nitrogen and phosphorus might have contributed to the availability of soil nutrients to plant growth whereby the nitrogen fertilization might contribute more vegetative growth

which leads late blooming. This result was agreed with Bewket and Netsanet (2021) who reported that increasing nitrogen and phosphorus fertilization levels significantly delayed days required reaching flowering on legume (soybean) plant.

Days to 80% maturity

The maximum period required to attain days to 80% maturity (99.33 days) was recorded from combined application of 150 kg ha⁻¹ NPS fertilizer and 40 cm inter row spacing, which was statistically similar to application of 150 kg ha⁻¹

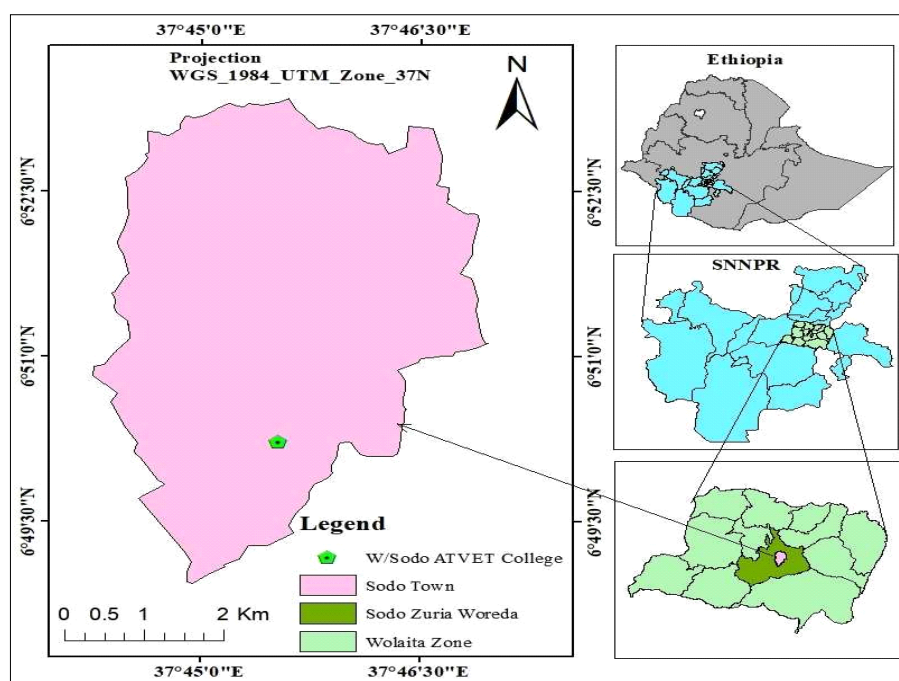


Fig 1: Map of the study area.

Table 1: ANOVA for growth and yield response of fenugreek to application of NPS fertilizer rates and inter-row spacing at Wolaita Sodo in 2022.

Variables	Rep	FR	SP	FR*SP	Error	CV
Degree of freedom	2	3	3	9	30	
Days to 50% flowering	0.75	67.72**	39.61**	2.14**	0.37	1.49
Days to 80% maturity	1.39	101.50**	47.83**	6.51**	0.57	0.82
Number of branch plant ⁻¹	3.6569	15.29**	7.31**	1.08**	0.076	6.16
Number of pods plant ⁻¹	3.168	119.40**	119.02**	7.29**	1.28	12.91
Pod length (cm)	3.62	10.73**	10.45**	0.4151ns	0.71	7.64
Number of seeds pod ⁻¹	0.0506	7.26**	18.57**	0.96ns	1.43	9.61
Single pod weight (g)	0.99	5.78**	6.25**	0.316ns	0.21	14.36
Thousand seed weight (g)	29.53	73.64**	72.09**	8.94ns	4.56	15.55
Seed yield per plant (g)	9.90	164.48**	39.3**	5.609**	0.49	10.58
Seed yield (t ha ⁻¹)	0.22	1.13**	0.39**	0.05**	0.015	14.56
Above ground biomass (t ha ⁻¹)	0.03	3.06**	5.175**	0.53**	0.11	18.19

**, * and ns indicate significant at $P < 0.05$; $P < 0.01$ and non-significant at $p < 0.05$, respectively. Rep= Replication, FR= NPS fertilizer rate, SP= Inter-row spacing and CV (%)= Coefficient of variation in per cent.

NPS fertilizer with 30 cm row spacing. Whereas, the shortest duration (87.33 days) was recorded from the control (Table 2). Days to maturity increased with increasing NPS fertilizer rate and inter row spacing. This might be due to less competition because of high availability of growth resources that promote luxurious growth and prolonged maturity. Moreover, it might 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 in agreement with Amanuel *et al.* (2018) who reported that increased rate of nitrogen stimulated haulm growth, prolonged the growing period and delayed pod formation (crop maturity). In contrary, Abera *et al.* (2019) have reported that application of phosphorus speed up fenugreek physiological maturity and reduce the number of days to physiological maturity by controlling some key enzyme reactions that involve in hastening crop maturity.

Number of branches per plants

Increasing rates of NPS fertilizer from 0 to 150 kg ha⁻¹ resulted progressive increase in the number of branches per plant. The maximum number of branch per plant (7.16) was recorded by the application of 150 kg ha⁻¹ NPS fertilizer with 40 cm inter row spacing which was statistically similar with the application of 150 kg ha⁻¹ NPS fertilizer with 30 cm inter row spacing. The minimum plant height (2.90) was recorded by 0 kg ha⁻¹ NPS fertilizer with 10 cm inter row spacing which was statistically on par with 20 cm and 30 cm spacing with zero fertilizer application (Table 3). The increase in number of branches with increase in NPS rate might be due to the fact that Phosphorus found in NPS fertilizer responsible for cell division activity, leading to the increase of plant height and number of branches. Nitrogen also involved in vegetative growth might contribute for

Table 2: Interactions effect of NPS fertilizer rates and inter-row spacing on phenology.

NPS fertilizer (kg ha ⁻¹)	Inter row spacing (cm)	Days to 50% flowering	Days to 70% pod formation	Days to 80% maturity
0	10	36.00 ⁱ	54.66 ⁱ	87.33 ^j
	20	37.33 ^h	55.00 ^{hi}	88.66 ⁱ
	30	39.00 ^g	55.00 ^{hi}	89.33 ^{hi}
	40	39.00 ^g	55.66 ^{gh}	90.00 ^{gh}
50	10	39.33 ^g	56.33 ^g	90.66 ^{fg}
	20	40.66 ^{ef}	57.33 ^f	91.00 ^{fg}
	30	41.33 ^{de}	57.33 ^f	91.33 ^{ef}
	40	41.66 ^{cde}	58.66 ^{de}	92.33 ^{de}
100	10	39.33 ^g	58.00 ^{ef}	91.33 ^{ef}
	20	42.00 ^{cd}	59.33 ^{cd}	91.66 ^{ef}
	30	42.66 ^c	60.00 ^c	95.00 ^c
	40	44.00 ^b	61.3 ^b	95.00 ^c
150	10	39.66 ^{fg}	58.6 ^{de}	91.66 ^{ef}
	20	42.66 ^c	60.00 ^c	93.00 ^d
	30	45.33 ^a	61.66 ^{ab}	98.33 ^a
	40	46.00 ^a	62.33 ^a	99.33 ^a
LSD _(0.05)		1.01	0.98	1.26
CV (%)		1.49	1.02	0.82

Means followed by same letter are non-significant at 5% probability, CV= Coefficient of variation, LSD= Least significant difference at 5% probability level.

Table 3: Number of branches per plant (NBPP) as influenced by interactions effect of NPS fertilizer rates and inter-row spacing.

Inter row spacing (cm)	NPS fertilizer (kg ha ⁻¹)							
	Number of pods per plant				Number of branches per plant			
	0	50	100	150	0	50	100	150
10	2.90 ^k	5.36 ^{ghij}	5.20 ^{hij}	6.96 ^{gh}	2.90 ⁱ	3.46 ^{gh}	3.80 ^{ef}	4.00 ^a
20	3.80 ^{jk}	7.23 ^{fg}	10.10 ^{de}	8.63 ^{ef}	3.06 ^{hi}	3.86 ^{ef}	4.90 ^d	4.96 ^d
30	5.06 ^{ij}	9.33 ^e	12.50 ^{bc}	14.16 ^b	3.20 ^{ghi}	3.80 ^{ef}	5.43 ^c	5.43 ^c
40	6.23 ^{ghi}	11.80 ^{cd}	14.00 ^b	17.10 ^a	3.63 ^{efg}	4.63 ^d	6.06 ^b	7.16 ^a
LSD _(0.05)		1.89				0.46		
CV (%)		12.91				6.16		

Means followed by same letter are non-significant at 5% probability, CV= Coefficient of variation, LSD= Least significant difference at 5% probability level.

branching. In line with the current investigation, Chala *et al.* (2021) also reported that increased number of branches of fenugreek with increasing NPS levels up to 200 kg ha⁻¹. Similarly, on mung bean, Nuru (2020) reported that the highest number of branches per plant by 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). Likewise, Data *et al.* (2005) reported that increased number of branches of fenugreek with increasing nitrogen levels up to 50 kg ha⁻¹. This finding is consistent with Hailu (2021) and Gemechu and Solomon (2021) who found that greater spacing increased the number of branches per plant in mung bean and common bean, respectively.

Number of pods per plant

The current investigation revealed that the highest number of pods per plant (17.10) was recorded by application of 150 kg ha⁻¹ NPS fertilizer with 40 cm inter row spacing. The lowest pod number per plant (2.90) was observed by 10 cm inter-row spacing with zero NPS fertilizer (Table 3). Increasing NPS rates and inter row spacing increases pod number positively. This might be because of the presence of N, P and S in blended form which highly involved in pod initiation and formation in fenugreek plants and the fact that improved availability of N, P and S enhances the canopy developments which in turn improve better solar radiation use through photosynthesis, thereby improving dry matter accumulation which later re-translocate to yield forming traits such as number of pods per plant. In addition it might be also due to more free space between plants at the wider inters row spacing and less inter-plant competition for available resources which helped more dry matter production that resulted in higher pod number. The current result was in agreement with the finding of Habib *et al.* (2019) who reported that pod number of fenugreek was significantly affected by both nitrogen fertilizer and inter-row spacing. Likewise, Zandi *et al.* (2011) also observed that number of pod per plant of fenugreek increase with increasing combination of nitrogen and spacing.

Number of seeds per pod

According to the current finding, the highest number of seed per pod (13.47) was recorded for the highest rate of NPS application (150 kg ha⁻¹), which was statistically on par with 100 kg NPS ha⁻¹ fertilizer rate (12.70) whereas the lowest (11.70) was obtained by the control plot (Table 4). The possible reason might be due to increased NPS fertilizer application that resulted in high rate of P contributed for seed development. In line with Baza (2019) and Chala *et al.* (2021) who reported that increasing NPS fertilizer rates increases number of seed per pod of mung bean and fenugreek varieties, respectively.

On the other hand maximum number of seed per pod (13.80) was obtained by 40 cm inter row spacing and minimum number of seed per pod (10.80) recorded by 10 cm inter row spacing. This indicates that decreases in plant density increased number of seeds per pod of fenugreek. The possible reason might be widely spaced plants encounter less inter plant competition than closely spaced plants and thus exhibit better growth and access to available resources that contributed to more number of seeds per pod. Also, Gemechu and Solomon (2021) observed that the quantity of seeds per pod increased when plant density of common bean decreased, which is consistent with the current finding.

Pod length (cm)

Data recorded on pod length of fenugreek indicated that both NPS fertilizer rate and inter row spacing highly significantly ($P < 0.05$) influenced pod length of fenugreek, while their interaction was non-significant (Table 1). The highest pod length (11.87 cm) was recorded with application of 150 kg NPS ha⁻¹ which was statistically on par with 100 kg NPS ha⁻¹ fertilizer rate (11.70 cm). The lowest pod length (9.79 cm) was obtained by the control plot (Table 4). This result indicated adequate supply of macro nutrients have greater contribution in vegetative growth and increasing pod length. In agreement with the current findings, it has been reported that increasing NP promoted pods and

Table 4: Effect of NPS fertilizer rates and inter-rows spacing on yield contributing characters of fenugreek.

NPS fertilizer (kg ha ⁻¹)	Seed pod ⁻¹	Pod length (cm)	Pod weight (g)	TSW (g)
0	11.70 ^b	9.79 ^c	2.29 ^c	11.26 ^c
50	12.05 ^b	10.95 ^b	3.13 ^b	12.24 ^c
100	12.70 ^{ab}	11.70 ^a	3.53 ^a	14.70 ^b
150	13.47 ^a	11.87 ^a	3.90 ^a	16.75 ^a
Inter row spacing (cm)				
10	10.80 ^c	9.87 ^c	2.38 ^d	11.05 ^c
20	12.54 ^b	10.97 ^b	2.88 ^c	12.60 ^c
30	12.80 ^{ab}	11.36 ^b	3.60 ^b	14.60 ^b
40	13.80 ^a	12.10 ^a	3.99 ^a	16.70 ^a
LSD _(0.05)	1.00	0.70	0.38	1.78
CV (%)	9.61	7.64	14.36	15.55

Means followed by same letter are non-significant at 5% probability, CV= Coefficient of variation, LSD= Least significant difference at 5% probability level.

seed formation in legumes (Sisay and Zenebe, 2021). Furthermore, Ozyazici (2020) documented that the highest pod length of fenugreek from higher dose of P than control treatment.

On the other hand, pod length of fenugreek differed highly significant due to inter row spacing. The highest pod length (12.10 cm) was recorded by the widest inter-row spacing (40 cm), whereas the shortest pod length (9.87 cm) was recorded by inter row spacing of 10 cm (Table 4). Increase in pod length with increasing inter row spacing could be due to the fact that at wider inter row spacing progressively enhanced the reproductive growth of the fenugreek plant. This suggestion is consistent with that of Reza (2021) who reported that pod length of fenugreek increased steadily with increases of spacing.

Single pod weight (g)

Analysis of variance indicated that both NPS fertilizer rate and inter row spacing highly significantly ($P < 0.05$) affected single pod weight of fenugreek. It was observed that single pod weight of fenugreek gradually increased with the increases of fertilizer doses. The maximum single pod weight (3.90 g) was recorded by the highest rate of NPS application (150 kg ha⁻¹) which was statistically on par with 100 kg NPS ha⁻¹ fertilizer rate (3.53 g) while the lowest (2.29 g) was obtained by the control (Table 4). This might be due to the optimum macro nutrients levels increased photosynthesis rate and translocation of foods from source to the developing sinks (pods) resulting bolder and heavier pods. Similarly, Habib *et al.* (2019) reported that increasing fertilizer doses increases fenugreek single pod weight.

Among the different inter row spacing, the widest inter row spacing (40 cm) showed the maximum weight (3.99 g). While the minimum weight (2.38 g) recorded from narrowest inter row spacing (10 cm) (Table 4). This finding was consistent with that of Reza (2021) who reported that pod weight of fenugreek increased steadily with increases of spacing.

Thousand seed weight (g)

The highest thousand seeds weight (16.75 g) was recorded by 150 kg NPS ha⁻¹ while the lowest thousand seed weight (11.26 g) was recorded by zero NPS fertilizer (Table 4). The increase in thousand seed weight with increased rate of macro nutrients application could be because of enhanced nutrient use efficiency by the crop at optimum levels of N, P and S from source to the developing sinks (seeds) resulting bolder and heavier seeds. The present study was in line with the findings of Chala *et al.* (2021) who reported that 100 seed weight increases with increases of NPS fertilizer rates of fenugreek.

On the other hand, thousand seed weight increasing with decreasing plant density. The highest thousand seed weight (16.70 g) was recorded by plant spacing of 40 cm while the lowest value (11.05 g) was obtained by 10 cm inter row spacing (Table 4). In line with Gemechu and Solomon (2021) who reported that 100 seed weight of common bean decreased with an increase in plant density. Moreover, Habib *et al.* (2019) reported that thousands seed weight of fenugreek increase with increasing row spacing.

Table 5: Interactions effect of NPS fertilizer rates and inter-row spacing on yield attributes of fenugreek at Wolaita Sodo, Ethiopia in 2022.

NPS fertilizer (kg ha ⁻¹)	Inter row spacing (cm)	TAGBM (t ha ⁻¹)	SYP(g)	SYH (t ha ⁻¹)
0	10	1.26 ^{ef}	1.34 ⁱ	0.57 ^{gh}
	20	1.11 ^f	1.83 ^{hi}	0.53 ^h
	30	1.10 ^f	2.89 ^{gh}	0.50 ^h
	40	1.07 ^f	3.28 ^{fg}	0.41 ^h
50	10	2.81 ^{bc}	4.23 ^f	0.91 ^{de}
	20	1.80 ^{de}	4.21 ^f	0.81 ^{ef}
	30	1.31 ^{ef}	5.46 ^e	0.61 ^{fgh}
	40	1.28 ^{ef}	6.53 ^{de}	0.58 ^{gh}
100	10	3.22 ^{ab}	6.14 ^{de}	1.10 ^{cd}
	20	2.30 ^{cd}	6.82 ^d	1.25 ^{bc}
	30	1.51 ^{ef}	9.73 ^c	0.92 ^{de}
	40	1.32 ^{ef}	10.28 ^{bc}	0.78 ^{efg}
150	10	3.46 ^a	6.95 ^c	1.36 ^b
	20	2.80 ^{bc}	11.33 ^b	1.60 ^a
	30	1.53 ^{ef}	12.57 ^a	0.93 ^{de}
	40	1.41 ^{ef}	13.70 ^a	0.91 ^{de}
LSD _(0.05)		0.57	1.17	0.20
CV (%)		18.19	10.58	14.56

Means followed by same letter are non-significant at 5% probability, CV= Coefficient of variation, LSD= Least significant difference at 5% probability level, TAGBM= Total above ground biomass, SYP= Seed yield per plant, SYH= Seed yield per hectare.

Table 6: Cost-benefit analysis of fenugreek production as influenced by NPS fertilizer rate and inter row spacing at Wolaita Sodo, Ethiopia in 2022.

Inter row spacing (cm) × NPS fertilizer rate (kg/ha)		TVC (ETB/ha)	NB (ETB/ha)	MRR (%)
10	0	4278	99528	-
	50	6804	158,202.0	2,322
	100	8770	189,230	1,578
	150	10764	234,036	2,247
20	0	2237	93,163.0	-
	50	4739	141,655.0	1,938
	100	6,806.4	218,773.6	3,730
	150	8,835.0	279,165.0	2,976
30	0	1551.2	75,082.0	-
	50	3984	107,022.0	1,312
	100	5998	160,808.0	2,670
	150	7896	160,710.0	D
40	0	1176.5	72,623.5	-
	50	3634.5	101,971.5	1,193
	100	5604.5	135,389.5	1,696
	150	7550.5	157,455.5	1,134

TVC= Total variable cost; MRR (%)= Marginal rate of return; NB= Net benefit; D= Dominated.

Total above ground biomass (t ha⁻¹)

The data analysis revealed that the maximum above ground biomass (3.46 t) was recorded by application of 150 kg ha⁻¹ NPS fertilizer rate with 10 cm inter row spacing which was statistically similar with application of 100 kg ha⁻¹ NPS fertilizer with 10 cm inter row distance. The minimum (1.07 t) was recorded by 0 kg ha⁻¹ NPS fertilizer rate with 40 cm inter row spacing which was statistically same as 20 cm and 10 cm spacing with no fertilizer application (Table 5). It can be inferred from the table that above ground biomass increased gradually with the increase of fertilizer doses and plant population. This might due to the availability of macro nutrients and their uptake with the combination of higher plant population that progressively increase the above ground biomass of the plant and sufficient supply of phosphorous from NPS that contributed to increase in the number of branches per plant. This result was in accordance with the investigation of Alemayehu and Shumi (2018) who reported a significant linear response of aboveground dry biomass yield faba bean to phosphorus application on acidic Nitisol. Moreover Alemu (2009) and Abera *et al.* (2019) reported that biomass yield of fenugreek increase with application of phosphorous from 0 to 26 kg ha⁻¹.

Seed yield per plant (g)

The analysis of variance investigation and result revealed that the maximum seed yield per plant (13.70 g) was recorded by application of 150 kg ha⁻¹ NPS fertilizer with 40 cm inter row spacing; statistically similar with application of 150 kg ha⁻¹ NPS fertilizer with 30 cm spacing. The minimum (1.34 g) was recorded by 0 kg ha⁻¹ NPS fertilizer rate with 10 cm inter row spacing which was statistically similar with

20 cm, 30 cm and 40 cm spacing with zero fertilizer application (Table 5). Increasing NPS rates and inter row spacing gradually increases seed yield per plant. This might be due to the availability of macro nutrients and enhanced more vegetative growth such as branches and yield contributing character such as number of pods.in addition also due to more free space between plants at the wider inters row spacing and less inter-plant competition for available resources. In harmony with the current result, Tuncturk (2011) and Reza (2021) reported that seed yield per plant of fenugreek increase with increasing spacing.

Seed yield per hectare (t ha⁻¹)

Analysis of variance revealed that seed yield per hectare of fenugreek was very highly significantly ($P < 0.05$) affected by main effects of NPS fertilizer rate, inter row spacing and their interaction effect (Table 1). The highest total seed yield (1.60 t) was obtained by the application of 150 kg ha⁻¹ NPS fertilizer with 20 cm inter row spacing followed by (1.36 t) obtained by the same rate of NPS combined with 10 cm row spacing. The lowest yield (0.41 t) was recorded by 40 cm inter row spacing combined with zero fertilized treatment (Table 5).

This might indicate that seed yield per hectare increased gradually with the increase of fertilizer doses and higher plant population. This might be due to higher availability of macro nutrients with the interaction of higher plant population that progressively enhanced the plant growth attributes, seed yield contributing characters and yield attributes of fenugreek. This result is conformity with Dubey *et al.* (2012) who reported that seed yield increase due to increase in plant growth attributes and yield

components. Despite the reduced growth and development of individual plants, the seed yield per unit area increases due to increased number of plants per unit area. In line with the current investigation, Zandi (2011) and Tuncturk *et al.* (2011) reported that seed yield of fenugreek increase with increasing levels of fertilizer doses with population density combination and found that the maximum seed yields were obtained from the higher fertilizer dose and closer row spacing treatments.

Economic analysis

The economic analysis revealed that the highest net benefit (279,130 ETB ha⁻¹) with 2,976% MRR was obtained by 20 cm inter row spacing with application of 150 kg NPS ha⁻¹ followed by net benefit of 234,036 ETB ha⁻¹ with 2,247% MRR obtained from combination of 10 cm inter row spacing with the same rate of fertilizer application and net benefit of 218,673.6 ETB ha⁻¹ with 3,730% MRR was obtained from combination of 20 cm inter row spacing with application of 100 kg NPS ha⁻¹ (Table 6). In line with this result, Abdi (2020) and Chala *et al.* (2021) obtained highest net benefit with the application of 150 kg NPS ha⁻¹ for fenugreek (Chala variety) and common bean, respectively.

CONCLUSION AND RECOMMENDATION

According to the current investigation, the application of 150 kg NPS ha⁻¹ was found to be superior for most of growth and yield component parameters in fenugreek. Regarding economic yield, the highest total seed yield (1.60 t) was obtained by the application of 150 kg ha⁻¹ NPS fertilizer with 20 cm inter row spacing followed by (1.36 t) obtained by the same rate of NPS combined with 10 cm inter row spacing. The economic analysis further revealed the highest net benefit (279,130 ETB ha⁻¹) with MRR of 2,976% recorded by 20 cm inter row spacing with application of 150 kg NPS ha⁻¹. Therefore, it could be recommended that applications of 150 kg ha⁻¹ NPS fertilizer combined with 20 cm inter row spacing was optimum for fenugreek productivity in the study area and areas with similar agro ecologies and soil conditions.

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Data availability

The data used for analysis and interpretation of the current study were all included in the manuscript.

Conflict of interest

The authors declare no conflicts of interest.

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