Optimization of Nitrogen and Phosphorus Fertilizer Rates for Improved Snap Bean (*Phaseolus vulgaris* L.) Growth, Yield and Quality

Melkamu Hinsermu*, and Selamawit Ketema
Ethiopian Institute of Agricultural Research, PO Box: 2003--Melkassa Agricultural Research Center, Ethiopia; Corresponding Author: melkamuhinsermu12@gmail.com

Abstract

Snap bean (Phaseolus vulgaris L.) is a significant vegetable crop in Ethiopia, serving as both an exportable commodity and a vital protein source for consumers. However, its current national productivity of 4.12 t ha^{-1} falls below its potential due to inadequate soil fertility. To address this issue, a field experiment was conducted at Melkassa Agricultural Research Center and Bishola in 2020 and 2021, respectively, with the objective of assessing the impact of nitrogen and phosphorus fertilizer rates on the growth, yield, and quality of snap bean. The experiment employed a 5x4 factorial design within a Randomized Complete Block Design (RCBD) framework, comprising five nitrogen fertilizer rates (control, 46, 92,138 and 184 N kg ha^{-1}) and four phosphorus fertilizer rates (control, 46, 92, and 138 P_2O_5 kg ha^{-1}). Statistical analysis revealed significant ($p \leq 0.05$) interactive effects of nitrogen and phosphorus fertilizer rates on marketable and total yield at the Bishola location. In 2020, at the Melkassa site, nitrogen fertilizer rates exhibited significant ($P \leq 0.05$) variations in total yield. However, neither nitrogen nor phosphorus fertilizers, nor their interaction, showed significant differences in pod weight per plant, pod length, and pod diameter at both Melkassa and Bishola. Notably, nitrogen fertilizer application demonstrated a significant impact on chlorophyll content and plant height at the Bishola location. The highest marketable and total yields were observed with nitrogen fertilizer rates of 46 and 138 N kg ha^{-1} at the Bishola location. Economic analysis, as reflected in the partial budget assessment, identified the application of a 46 N kg ha^{-1} fertilizer rate as the optimal treatment, resulting in the highest net benefits of 234,480 ETB ha^{-1} and an acceptable marginal rate of returns for snap bean production in the central rift valley of Ethiopia, where similar soil properties exist. In conclusion, optimizing nitrogen and phosphorus fertilizer rates can significantly enhance the growth, yield, and quality of snap bean crops. The findings of this study provide valuable insights for farmers and policymakers alike, with the potential to improve snap bean productivity and contribute to the agricultural development of Ethiopia's central rift valley region.

Keywords: Soil fertility, snap bean productivity, central rift valley,

Introduction

Snap bean (*Phaseolus vulgaris* L.) comprises a group of common bean that has been selected for succulent pods with reduced fiber primarily grown for its young edible and fleshly pods. The immature pods and seeds are produced and marketed as fresh, canned or frozen products (Getachew, 2006; Kenneth, 2012). It is the most important vegetable crop, which is rich in protein, carbohydrates, calcium, vitamins, and amino acids (Ghonimy *et al.,* 2009).

In 2017, world total production of snap bean was 24,221,252 t from total area of 1,579,971 ha. In Africa, production of snap bean was 756,345 t from total area of 81,272 ha, while in Ethiopia, production of snap bean was 7,384 t from total area of 1,801 ha. In 2017, Ethiopia exported an estimated amount of 1,273 t of snap bean mainly to Europe and the Middle East, bringing a considerable amount of foreign currency to the country (FAOSTAT, 2018).

Snap bean is primarily demanded during the European winter season and its production in Ethiopia is under irrigation during the dry season. Snap bean production in Ethiopia has increased from time to time both for export and local markets (Hussein *et al*., 2015). Thus, currently, snap bean is one of the most important vegetable crops that are extensively produced for export with the highest share (94%) among all vegetables (Lemma *et al*., 2006; Lemma, 2011). In addition, recently, it is becoming an important vegetable in big hotels, festivals, and in making various dishes such as a side vegetable, soup and salads with vegetables (Lemma *et al*., 2006).

Despite the fact that there exists more or less suitable edaphic and climatic condition in Ethiopia for snap bean production, the productivity and quality remained low and poor (Amberber, 2013; Graham *et al*., 2013). The national average pod yield of smallholder snap bean productivity in Ethiopia was 4.12 t ha^{-1}, which is low (Tesfaye, 2017) compared to the world average productivity of about 14.22 t ha^{-1} (CIAT, 2006). Production constraints such as lack of improved varieties, poor cultural, water and nutrient management practices are the key factors for the low productivity and poor quality of snap bean production in Ethiopia (Girma, 2009). Among these constraints low soil fertility has been indicated as the major abiotic constraint to snap bean production in Ethiopia (Tesfaye, 2017).

Declining soil fertility is a major problem in snap bean production in Eastern Africa, particularly snap beans producing areas in Ethiopia (Lunze *et al*., 2007; Tesfaye, 2017). Among the essential nutrients, nitrogen and phosphorus are limiting factors for snap bean production (Daiana *et al*., 2014). The nitrogen requirement of snap bean plant is high, due to its weak fixation capacity of atmospheric N compared to other legumes (Feleafel and Mirdad, 2014). Snap beans lack

NOD genes, hence it does not have nodulation and this makes them poor in symbiotic nitrogen fixing (Kushwaha, 1994). Because of this poor nodulation in snap beans, nitrogen and phosphorus is greatly needed for good establishment of roots, nodulation and growth. Application of 100 kg N ha^{-1} increased fresh pod yield by 42% as compared to the control (Hussein *et al*., 2015). Application of 120 and 60 kg ha^{-1} nitrogen and phosphorus fertilizers, respectively increased number of pods $plant^{-1}$ of snap bean (Kumar *et al.* 2004). Inadequate supply of nitrogen leads to reduced growth, lower dry matter production, decrease leaf area and roots, reduced light interception, limited yield and early crop senescence (Bertossi *et al*., 2013).

In the tropical region, like Ethiopia, the amount of available phosphorus in soils is largely insufficient to meet the demand of beans and thus, phosphorus deficiency is prevalent in bean crops due to high fixation (Azmera and Pellegrino, 2017). Phosphorus deficiency can reduce snap bean pod yield by 60 to 75% (Snapp *et al*., 2002). Tesfaye (2017) stated that application of 92/69 N P_2O_5 kg ha^{-1} gave the highest yield in snap bean. Phosphorus deficiency is widespread due to the low P-status of the parent material and long-term anthropogenic mismanagement through imbalance between nutrient inputs and exports and P loss by soil erosion (Fouda, 2017). Total phosphorus in the soils is very high, but only around 10% of applied phosphorus is immediately available for plants, the rest converted into insoluble compounds or adsorbed to soil particles (Liu *et al*., 1994). Phosphorus fertilization improves quality of vegetable fruits because increases their resistance to diseases as well as drought and adverse environmental conditions (Emam *et al*., 2018). Hence, the current study was conducted to evaluate the effects of nitrogen and phosphorus fertilizer rates on growth, yield and quality of snap bean and to determine economically optimum nitrogen and phosphorus fertilizers rate for snap bean production.

Materials and Methods

Description of study area

The experiment was conducted at Melkassa Agricultural Research Center and Bishola during 2020 and 2021. The site is found 117 km South East of Addis Ababa with geographic co-ordinate of $8^o24'$N latitude and $39^o12'$E longitude. It situated at an altitude of 1550 m.a.s.l. The area receives mean annual rainfall of 763mm, about 70% of which received during the main rain season from June to September. The mean annual maximum and minimum temperature of the site is about 28.6^0C and 13.8^0C, respectively. The agro-climatic condition of the area is classifies as semi-arid. The soil texture is dominantly loam and clay loam (MARC, 1994). Available soil water lies between 34.04% at field capacity and 16.74% at permanent wilting point on dry weight basis. The average bulk density of the soil in depth of 0-90cm is 1.13g/cm^3. The soil is slightly alkaline ranging from 7.4-7.6 pH (Mesfine *et al.*, 2005).

Bishola site is found 123 km south East of Addis Ababa at the geographical location 8^{o}37'N latitude and 39^{o}37'E longitude. at an altitude of 1585 m.a.s.l. The area is characterized as a semiarid area. Mean annual rainfall varies between 512 and 1345 mm. The mean annual temperature is 21.2^{o}C with a mean minimum temperature of 14 C and a mean maximum temperature of 28.4 C. The type of soil is classified as Andosols with pH of 7.2, total nitrogen 0.3%, organic carbon 0.04% and available Phosphorous 1.5 mg/kg soil (Esayas et al., 2005).

Experimental Design and Treatment

The experimental design employed in this study was a 5x4 factorial arrangement within a Randomized Complete Block Design (RCBD) framework, consisting of three replications. The factorial design incorporated five different nitrogen fertilizer rates (control, 46, 92, 138 and 184 N kg ha^{-1}) and four phosphorus fertilizer rates (control, 46, 92 and 138 P_2O_5 kg ha^{-1}). Each plot had an area of 6 m^2, with dimensions of 3 m in length and 2 m in width. The spacing between individual plots and blocks was set at 1.5m for both dimensions, providing adequate separation for the experimental units.

Experimental Procedures

The land preparation involved plowing using a tractor, followed by disking and harrowing to ensure proper soil preparation. All cultural practices, including weeding and cultivation, were uniformly applied to all plots. For the experiment, the well-adapted and high-yielding snap bean variety 'plati' was selected. The planting was carried out with a spacing of 40 cm between rows and 10 cm between individual plants, ensuring appropriate plant density and arrangement. Plant population was maintained by sowing two seeds/hill at 5cm depth and thinning to one upon appearance of trifoliate leaves. Phosphorus fertilizers was applied at sowing time in the form of triple super phosphate (TSP: 46% P_2O_5). Nitrogen fertilizer in the form of urea (46% N) was applied in two splits; 50% at sowing time and 50% at pre-flowering stages. All other necessary agronomic managements practices were carried out properly and equally for all treatments.

Soil samples and analysis

Soil sample was collected from representative twelve spots from the entire experimental sites by using diagonal sampling method before planting by using auger at depth of 0-30cm, then composite samples were subjected to physical and chemical analysis. The soil samples were air dried and ground fine by using mortar and pestle. The soil sample was sieved and passed through 2 mm sieve size and analyzed for physical properties (soil texture was analyzed by using Bouyoucos hydrometer method and the textural class was determined by using the soil textural triangle (Anderson and Ingram, 1993). Bulk density (g/cm^3) was done by using core sampler. Chemical properties (exchangeable capacity (ds m^{-1})) were analyzed by using EC meter 4510 Jenway. Total nitrogen (%) by using Micro-Kjeldahl digestion method with sulfuric acid. Organic matter (%) was analyzed by using Muffle furnace at 440^0c (Yadav *et al*., 1996). Available phosphorus (ppm) was determined by the Olsen's method using a spectrophotometer and pH was determined on a 1:2.5 soil: H_2O suspension with a glass electrode pH meter (Jackson, 1973). Soil analysis was done at Melkassa and Hort coop PLC soil laboratory.

Data to be collected

Plant height (cm) was measured from the base of the plant to the apical bud of plant at the second harvest from five plants in each plot by using meter. Leaf chlorophyll content (µmol m^{-2}); was determined by using SPAD (Minolta SPAD-502, Konica Minolta Sensing, Inc. Japan) from recently fully expanded mature upper leaf of three plants in each plot. Number of pods per plant was determined by counting the number of pods of three plants randomly selected from each plot. Total pods yield (kg), marketable yield (kg) and unmarketable yield (kg) were recorded from harvests made on 2^{nd} and 3^{rd} rows. Pod length (cm) was measured from the initial pods where emerge to the tip of the pods from the mean of five pods randomly selected from five plants in each plot using ruler. Pod diameter (cm) was determined from the mean of five pods randomly selected from five plants in each plot using sieve by inserting the pods into the appropriate whole best fitting for the pod size. Average weights of pods per plant (g) were recorded from mean of ten pods.

Partial Budget Analysis

The annual operating variable cost including fertilizer cost and labor cost was estimated (Ortega *et al.,* 2004). The gross return for fertilizers (N and P) rates was calculated using the marketable pod yield and current wholesale prices. Subsequently, the net and gross return for snap bean production at different N and P fertilizer rates was estimated (Imtiyaz *et al*., 2000).

Results and Discussion

Physico-chemical properties of the soil

Physical soil properties

The soil textural class at both locations over the two-year period was determined to be sandy loam. The soil pH measured at Melkassa and Bishola was 7.40, indicating a moderately alkaline condition (Motsara and Roy, 2008) in Table 1.

Table 1. Physical soil properties of experimental field before sowing

Location	Texture Result				
	pH	% clay content	% silt content	% sand content	Classification
MARC (2020)	7.5	16.25	25.00	58.75	sandy loam
MARC (2021)	7.33	12.50	32.50	55.00	sandy loam
Bishola (2020)	7.48	11.25	20.00	68.75	sandy loam
Bishola (2021)	7.6	15.31	23.44	61.25	sandy loam

Chemical soil properties

The electrical conductivity of the soil samples tested indicated the absence of salinity. However, the levels of organic carbon and organic matter (OM) were rated as low according to Hazelton and Murphy (2007). Similarly, the total nitrogen content was found to be low. On the other hand, the available phosphorus (P) content was rated as high, as indicated in Table 2.

Table 2. Chemical soil properties of experimental field before sowing

Location	EC (µS/cm)	CEC (meq/L)	%TOC	%OM	%TN	Ca mg/kg	Mg mg/kg	K mg/kg	S mg/kg	P mg/kg
MARC (2020)	170	25.56	1.07	1.85	0.11	5,004.01	428.46	1,287.97	10.05	14.28
MARC (2021)	214	13.86	1.19	2.06	0.09	8,299.39	454.43	1,517.32	33.62	50.40
Bishola (2020)	313	26.28	1.68	2.90	0.10	11,848.80	278.06	1,165.55	23.03	12.98
Bishola (2021)	148	27.06	1.38	2.38	0.25	3,843.12	550.85	1,152.74	10.03	15.33

Vegetative and quality parameters

Plant height

The main effect of nitrogen and phosphorus fertilizer rates, as well as their interaction, did not demonstrate a significant difference in plant height at Melkassa. This lack of significance could be attributed to the substantial residual accumulation of nitrogen and phosphorus in the soil. However, in the case of Bishola, varying nitrogen fertilizer rates did exhibit a notable effect on plant height. Specifically, the tallest plants were observed when nitrogen was applied at rates of 92, 138, and 184 kg/ha, whereas the shortest plants were found in the control group without nitrogen supplementation. This outcome suggests that increasing nitrogen rates positively influenced plant height (Bertossi *et al*., 2013).

Chlorophyll content

The main effects of nitrogen and phosphorus fertilizers rates and their interaction showed non-significant effect on chlorophyll content at Melkassa. But, at Bishola nitrogen fertilizer rates showed significant effect on chlorophyll content. The higher chlorophyll contents were obtained at 138 (50.25 (µmol m^{-2}) and 184 N kg/ha (49.68 (µmol m^{-2}), while the lowest was recorded from the control 0 N kg/ha (46.34 (µmol m^{-2}).

Table 3. Vegetative performance and quality of snap bean influenced by N and P fertilizers rates application at Melkassa

N (kg/ha)	Plant height (cm)	Chlorophyll content (µmol m^{-2})	Pod weight/plant (g)	Pod length (cm)	Pod diameter (mm)
0	46.08	45.63	58.70	13.41	7.30
46	48.01	46.08	59.63	13.66	8.80
92	48.00	46.20	62.72	13.72	7.63
138	48.96	46.22	65.42	14.15	7.89
184	48.72	47.97	57.58	13.00	7.03
F-test	NS	NS	NS	NS	NS
P_2O_5 (kg/ha)					
0	47.37	45.97	58.92	13.42	7.42
46	46.65	45.18	57.82	13.40	7.53
92	48.20	48.43	66.51	14.04	8.66
138	49.52	46.10	60.00	13.44	7.32
F-test	NS	NS	NS	NS	NS
CV (%)	8.85	8.74	18.91	14.91	23.40

Means followed by the same letter are not significantly different at p < 0.05

Pod length, diameter and weight

The main effects of nitrogen and phosphorus fertilizers rates and their interaction showed non-significant effect on pod length and diameter at both locations (Melkassa and Bishola).

Table 4. Vegetative performance and quality of snap bean influenced by N and P fertilizers rates application at Bishola

N (kg/ha)	Plant height (cm)	Chlorophyll content (µmol m^{-2})	Pod weight/plant (g)	Pod length (cm)	Pod diameter (mm)
0	44.30^{b}	46.34^{c}	55.95	12.97	7.36
46	47.72^{ab}	47.05^{bc}	56.95	13.34	7.52
92	50.17^{a}	49.44^{ab}	57.78	12.95	7.46
138	50.23^{a}	50.25^{a}	59.43	13.50	7.45
184	51.50^{a}	49.68^{a}	60.41	13.03	7.43
F-test	**	**	NS	NS	NS
P_2O_5 (kg/ha)					
0	47.47	48.05	59.05	13.41	7.41
46	48.68	49.20	60.15	12.90	7.42
92	48.72	48.82	56.98	13.09	7.49
138	50.27	48.14	56.22	13.23	7.47
F-test	NS	NS	NS	NS	NS
CV	9.62	5.88	11.01	6.04	2.65

Means followed by the same letter are not significantly different at p < 0.05

Marketable and total yield

The main effects of nitrogen, and phosphorus fertilizers rates and their interaction showed non-significant effects on marketable and total pod yield of snap bean at Melkassa during 2021. In 2020, at Melkassa nitrogen fertilizer rates showed significant ($P \leq 0.05$) difference on total yield. The highest total yield was recorded at 184 N kg/ha (177.50 q/ha) followed by 138 N kg/ha (171.63 q/ha), while lowest total yield was obtained from control 0 N kg/ha (130.49 q/ha). According to Andrea *et al.* (2008), N application increased the vegetative growth, fresh and dry weight pods, reproductive parts were increased. The combined analysis of variance indicated that a non-significant effect on marketable and total pod yield was obtained at Melkassa.

The interaction effect of nitrogen and phosphorus fertilizers rates had brought significant ($P \leq 0.05$) effect on marketable and total yield at Bishola location. Higher marketable yield was recorded from interaction of 184 N kg/ha and 46 P_2O_5 kg/ha (153.95 q/ha) followed by 92 N kg/ha and 92 P_2O_5 kg/ha (146.05q/ha), 138 N kg/ha and 138 P_2O_5 kg/ha (153.26 q/ha), whereas lowest marketable yield was obtained from application of the 46 P_2O_5 kg/ha (74.06 q/ha). Similar trend was observed for the total yield.

Table 5. Combined marketable and total yield influenced by N and P fertilizers rates application at Melkassa during 2020 and 2021

N (kg/ha)	Marketable yield (q/ha)			Total yield (q/ha)		
	2020	2021	Combined	2020	2021	Combined
0	104.12	131.76	117.9	130.49c	156.81	143.7
46	112.39	145.00	128.7	139.41bc	172.65	156.0
92	117.24	149.91	133.6	145.61abc	179.32	162.5
138	135.51	143.02	139.3	171.63ab	168.70	170.2
184	141.53	124.42	133.0	177.50a	148.22	162.9
F-test	NS	NS	NS	*	NS	NS
P_2O_5 (kg/ha)						
0	107.06	148.98	128.0	138.72	177.59	158.2
46	119.27	130.58	124.9	150.53	156.05	153.3
92	135.04	133.32	134.2	158.52	157.26	157.9
138	127.25	142.41	134.8	163.95	169.66	166.8
F-test	NS	NS	NS	NS	NS	NS
CV	30.20	27.07	28.6	28.68	25.21	26.9

Means followed by the same letter are not significantly different at $p < 0.05$

Table 6. Interaction effect of marketable and total yield influenced by N and P fertilizers rates application at Bishola during 2020 and 2021

P_2O_5 (kg/ha)	Marketable yield (q/ha)					Total yield (q/ha)				
	N (kg ha^{-1})									
	0	46	92	138	184	0	46	92	138	184
0	81.91^{ef}	131.10^{a-d}	126.39^{a-d}	142.99^{abc}	137.09^{a-d}	106.61^{ef}	158.23^{a-d}	153.39^{a-d}	169.49^{a-d}	167.17^{a-d}
46	74.06^{f}	106.77^{c-f}	142.99^{abc}	122.68^{a-d}	153.95^{a}	89.56^{f}	132.35^{c-f}	167.96^{a-d}	152.44^{a-d}	193.53^{a}
92	134.12^{a-d}	142.84^{abc}	114.08^{b-e}	146.05^{ab}	136.79^{a-d}	156.50^{a-d}	170.10^{a-d}	133.75^{cde}	171.23^{abc}	165.89^{a-d}
138	120.25^{a-d}	117.49^{a-e}	103.55^{def}	153.26^{a}	144.51^{abc}	144.36^{cde}	148.10^{b-e}	126.28^{def}	190.30^{ab}	173.66^{a-d}
F-test			**					*		
CV (%)			26.39					24.91		

Means followed by the same letter are not significantly different at $p < 0.05$

Partial budget analysis

The partial budget analysis indicated that the best treatment was 46 N kg/ha fertilizer rate application, which gave highest net benefits of 234,480 ETB ha^{-1} and also the second alternative recommendation was 138 N kg/ha, which gave 252,882 ETB ha^{-1} net benefits with an acceptable marginal rate of returns for snap bean production (Table 7).

Table 7. Dominance analysis and marginal rate of returns of interaction effect of N & P fertilizers rate applications on marketable pod yield of snap bean

$N*P_2O_5$ (kg/ha)	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Dominance	Marginal cost (ETB ha^{-1})	Marginal benefit (ETB ha^{-1})	MRR (%)
0*0	0	147438				
46*0	1500	234480		1500	87042	5802.8
0*46	2000	131308	Dominated			
92*0	3000	224502	Dominated			
46*46	3500	188686	Dominated			
0*92	4000	237416		2500	2936	117.44
138*0	4500	252882		500	15466	3093.2
92*46	5000	252382	Dominated			
46*92	5500	251612	Dominated			
0*138	6000	210450	Dominated			
184*0	6000	240762	Dominated			
138*46	6500	214324	Dominated			
92*92	7000	198344	Dominated			
46*138	7500	203982	Dominated			
184*46	8000	269110		3500	16228	463.6571
138*92	8500	254390	Dominated			
92*138	9000	177390	Dominated			
184*92	10000	236222	Dominated			
138*138	10500	265368	Dominated			
184*138	12000	248118	Dominated			

Conclusion and Recommendations

Snap bean is a leading exportable vegetable crop and it is a protein source for consumers in many parts of Ethiopia. However, its' current national productivity of 4.12 t ha^{-1} is lower than its' potential as a result of low soil fertility. Therefore; the effect of nitrogen and phosphorus fertilizer rates on growth, yield and quality of snap bean, was studied to determine economically optimum nitrogen and phosphorus fertilizers rate for snap bean production.

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The analysis of variance conducted revealed that the interaction between nitrogen and phosphorus fertilizer rates had a significant ($P \leq 0.05$) impact on marketable and total yield at the Bishola location. In 2020, at

Melkassa, nitrogen fertilizer rates also exhibited a significant ($P \leq 0.05$) difference in total yield. However, there was no significant difference observed in pod weight per plant, pod length, and pod diameter at both Melkassa and Bishola when considering the main effects of nitrogen and phosphorus fertilizer rates, as well as their interaction. Conversely, the application of nitrogen fertilizer rates did show a significant difference in chlorophyll content and plant height at the Bishola location. The highest marketable and total yield were obtained when nitrogen was applied at rates of 46 and 138 kg/ha at the Bishola location. A partial budget analysis indicated that the most favorable treatment was the application of 46 kg/ha of nitrogen fertilizer, which resulted in the highest net benefits of 234,480 ETB/ha. This treatment also showed an acceptable marginal rate of return for snap bean production in the central rift valley of Ethiopia.

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