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Effect of NPS Rates and Row Spacing on Production of Faba Bean (*Viciafaba L*.) at High-land of North Shewa Zone of Oromia, Ethiopia

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Authors' contributions

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

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ABSTRACT

Plant density and poor soil fertility are among the major factors that limit faba bean production in the study areas. Therefore, a field experiment was conducted to determine the optimum NPS (nitrogen, phosphate, and sulfur with the ratio of 19% N, 38% P_2O_5, and 7% S) rate and appropriate inter-row spacing for faba bean production in the highlands of the north Shewa zone of Oromia, Ethiopia. Factorial combination of four rates of NPS (0, 50, 100, 150 kg ha^{-1}) and four inter-row spacing (30, 40, 50, 60cm) were laid out in a Randomized Compete Block Design (RCBD) with three replications. The result of the study indicated that the soil required amending with organic fertilizers to enhance soil fertility. Both the main and the interaction effects of NPS and inter-row spacing significantly influenced the faba bean phenological and growth parameters. However, NPS had more profound effects in enhancing the growth response of the crop than inter-row spacing. Increasing the rate of NPS from nil to 100 kg ha^{-1} resulted in a 30% increase in grain yield, with no further increases noted beyond this level. However, the result revealed that increased inter-row

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spacing from 30cm to 60cm decreased grain yield. Decreasing inter-row spacing implies high plant density, which consequently correlates with high yield. The total yield per unit area depends not only on the performance of individual plants but also on the density of plants per unit area, as confirmed in this study. The maximum net benefit of 91,639.5 ETB ha^{-1} with an acceptable marginal rate of return 486.3% was obtained from the application of 100 kg ha^{-1} NPS rate and 30 cm inter-row spacing. Thus, this rate and inter-row spacing are suggested for faba bean production in the north shewa zone.

Keywords: Faba bean; fertilizer; row spacing; soil fertility; bean production; organic fertilizers.

1. INTRODUCTION

"Faba bean (*Viciafaba L.*) is the most important grain legume crop in terms of coverage, production, protein source, soil ameliorating, and cropping system in Ethiopia" [1]. "It is the second largest faba bean producer in the world next to China and accounts for 1.14 t ha^{-1} which is about12% of the world's area of production" [2,3]. "Currently, the crops occupy 31% of the area cultivated for pulses (1,863,445 ha) in the country" [3]. "However, the productivity of the crop in the country is low (2.12 t ha^{-1}) compared with the average yield (3.7 t ha^{-1}) obtained in major faba-bean-producing countries of the world" [3,4]. "The crops play a significant role for Ethiopian farmers as a source of food, feed, and cash crops. Despite the importance of the crop in traditional farming systems, the yield is generally low due to several factors, among which poor soil fertility and inadequate plant nutrition, untimely sowing, sub-optimal weed control, and the lack of improved varieties are the major ones" [1,5].

"The productivity of food legumes is constrained by low soil pH and the consequent low P availability. Due to a long cropping history and low manure and fertilizer inputs, the nutrient status of Ethiopian soils is generally low P is the most limiting nutrient in faba bean-producing areas. The previous research results indicated that soil fertility is a major constraint of faba bean production" [5,6]. "Although blanket application of 18/20 kg NP ha^{-1} in the form of DAP and spacing of 40 cm×10 cm to increase crop yield for about half a century has been recommended for faba bean production in the country, this was not substantiated by research results of soil fertility status and crop requirement" [7]. In agreement with this, Abebe et al*.* [8] reported that "the combined application of 46 kg P_2O_5 ha^{-1} and 24 kg K_2O ha^{-1} contributed a 38% more grain yield improvement in faba bean than the control treatment in western Ethiopia".

"Similarly, a 31% mean improvement in the grain yield of faba bean was reported due to the application of phosphorus fertilizer at 15, 30, 45, and 60 kg ha^{-1} compared with the control treatment in southern Ethiopia" [9]. "Plant population of faba bean is another important factor in the new reclaimed lands which depends on stand establishment. However, plant competition for environmental resources is affected by the spatial arrangement of those plants; this may be affected by the plant density (number of plants per unit area) by the distance between rows" [10]. "In Ethiopia, a standard spacing of 40 cm×10 cm has been adopted, irrespective of the growing conditions and locations" [11]. "However, most farmers are not sure of the appropriate planting density to use. They use either very high or very low plant density which consequently results in poor grain yield in quality and quantity" [12].

Since the interaction effects of fertilizer and inter-row spacing on faba beans are not well studied, this experiment was needed to establish practical recommendations for the area. Thalji [13] pointed that "seed yield increased as row spacing decreased". "On the other hand, in other studies, seed, pods, and straw yields per plant were increased by increasing row spacing" [14]. Even if northern Ethiopia is one of the major producing areas of faba bean, there is no awareness of proper plant population and phosphorus application that is important to increase faba bean production and productivity especially, in the north shewa zone. Therefore, the experiment was carried out to determine optimum NPS rates and appropriate inter-row spacing for faba bean production in the highlands of the north Shewa zone of Oromia, Ethiopia.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted in Degam district under rain-fed conditions during the 2021 and 2022 cropping seasons. The district is located at a distance of 125km from Addis Ababa, along Addis-Gojam main road. Degam district, comprising 18 rural kebele's and two urban kebele's, has an area of 686 km^2. The agro ecologies of the district are Dega, Weyina Dega, and Kola covered about 30%, 32%, and 38% of the total district's area, respectively. The three major soil types of the district are vertisols or black soils, red soil, and lime soil. The major crops grown in the district are barley, tef, oat, and wheat from cereals, faba beans, field peas, noug and linseed from pulses and oilseed crops, and potato and tomato from horticulture crops (Zonal ATLAS, 2006 E.C).

2.2 Experimental Materials

Faba bean variety known as Walki (EH96049-2) was used as a test crop. The variety has been released by Holeta Agricultural Research Center in 2008 and was released for water logging vertisol areas and moderately resistant to chocolate spot and rust. The variety was selected based on its adaptation and better performance in yield. The crop requires 700-1000 mm of rainfall and grows at an altitude of 1900-2800 meters above sea level. The variety required 49-62 days to flower and 133-146 days to reach maturity [15]. Phosphate fertilizer in the form of blended NPS in 100 kg ha^{-1} NPS (19% N, 38% P_2O_5, and 7% S) which was uniformly applied to all experimental plots except zero plots in different rates and inter-row spacing was used.

2.3 Treatments and Experimental Design

The treatments consisted of four NPS fertilizer rates (0, 50, 100, and 150 kg ha^{-1}) and four inter-row spacing (30, 40, 50, and 60 cm) with row numbers 8, 6, 5, and 4, respectively. The gross plot size was 7.2m^2 (3 x 2.4) and the distance between plots and replications were 1 and 1.5 m, respectively. The experiment was laid out as 4 x 4 in factorial combination in RCBD with three replications. Weeding and other agronomic practices were carried out as per recommendation for the crop. Fungicide natura and mancozeb were applied to control faba bean gall. The middle rows were harvested, dried, threshed and cleaned for data collection.

2.4 Soil Sampling and Analysis

Pre-planting soil samples were taken randomly in a zigzag pattern from the experimental plots at a depth of 0-30 cm according to the standard. The soil samples were composited, air dried passed through a 2 mm sieve, and analyzed in the laboratory for physico-chemical analysis. Soil samples after harvest of the crops were also collected from a depth of 0-30 cm near a root zone at four points from all experimental plots and composite as per treatments. The composite soil samples were analyzed for selected physico-chemical properties mainly for pH, total nitrogen, available phosphorous, organic matter, Cation exchange capacity (CEC), and soil texture. Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter by a potentiometer [16]. Available phosphorus content of soil samples was estimated by Olsen's method [17] and expressed in ppm. Total nitrogen was analyzed by the Micro-Kjeldahl digestion method with sulphuric acid and organic matter was determined by the volumetric method [18]. CEC was analyzed by the ammonium Acetate Method and expressed by (Cmol (+)/Kg soil) [16]. Soil Texture was determined by the hydrometer method according to FAO [16].

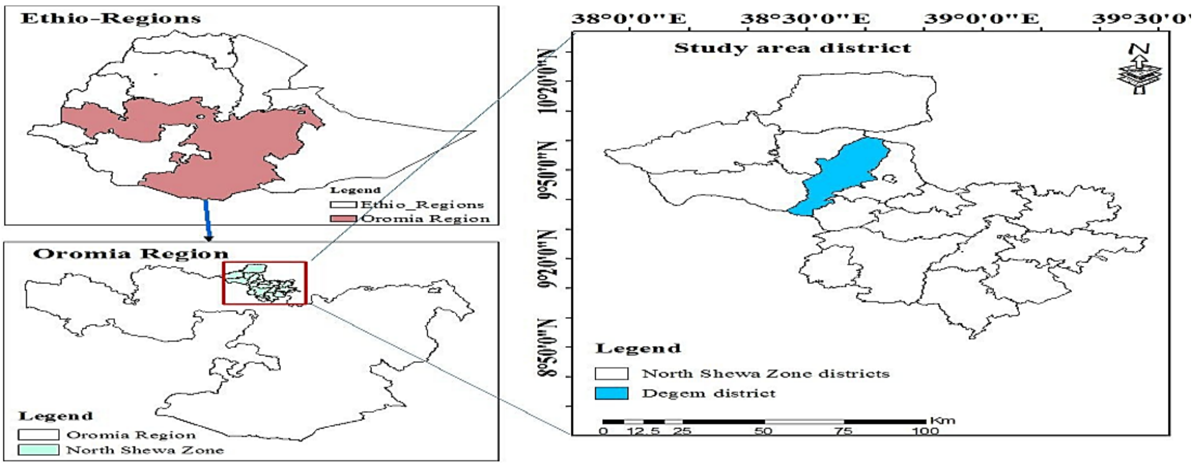

Fig. 1. Map of experimental district in north shewa, Oromia, Ethiopia

2.5 Data Collected

Days to 50% flowering: it was recorded as the number of days from planting to when 50% of the plants produced flower based on visual observation.

Days to 90% physiological maturity: this was recorded as the number of days from planting to when the plants attained 90% physiological maturity i.e. when the plants and the pods turned pale yellow in color based on visual observation.

Plant height (cm): the height of five randomly tagged plants from the net plot area was measured from ground to the tip and the mean were recorded as plant height at physiological maturity.

Number of primary tillers per plant: it was taken by counting the number of primary tillers from the main stem from randomly taken five plants at physiological maturity.

Number of pods per plant: it was recorded by counting the number of pods from randomly tagged five plants and their average was taken as number of pods per plant at harvest.

Number of seeds per plant: after pods counted from each of the five tagged plants the total number seed per plant was calculated as number of pod per plant multiplied by number of seed per pod.

Grain yield (kg ha^{-1}): Grain yield was measured by taking the weight of the grains from the net plot area converted to kilograms per hectare.

Above ground biomass yield (ton h^{-1}): At maturity, the whole plant parts of above ground, from the net plot area was harvested and after drying for three days, the total dry biomass was measured.

Hundred seed weight (g): The seed was being harvested and sundried for three days and hundred seed was counted and weighed that had been taken from the composited seeds at each plot.

Harvests index (HI): It is the ratio of economic yields to total above ground dry biomass yield [19].

2.6 Partial Budget Analysis

Partial budget analysis was conducted based on the average price fluctuation to investigate the economic feasibility of the treatments. Total costs that varied (TCV) among treatments were assessed. The cost of faba bean seed, the cost of NPS, and the cost of labor required for the application were estimated by assessing the current local market. Then, the amount of seed required was varied with inter and intra-row spacing and the market price of the seed (30 ETB kg^{-1}) at time of planting, the price of NPS (2146.5 ETB 100 kg^{-1}), and the cost of daily labor (75.00 ETB per man per day) based on the current government scale in the study area were used to get the total cost that varied among the treatments. Other non varied costs were not included since all management practices were uniformly applied to each experimental plot. The average yield was adjusted downwards by 10% to reflect the difference between the experimental yield and the expected yield of farmers from the same treatment. This is done because experimental yields, even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments. The net benefit and the marginal rate of return were calculated as per the standard manual [20].

2.7 Data Analysis

All the measured parameters were subjected to analysis of variance and computed using R software. The means were separated using the LSD test at a 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 Soil Physico-chemical Properties before Sowing

“Soil texture is an important soil physical characteristic as it determines the infiltration rate, water holding capacity of the soil, the ease of tilling, and the amount of aeration, and also influences soil fertility” [21]. According to the soil textural class determination triangle, the soil of the experimental site was found to be loam, with a proportion of 42% sand, 18% clay, and 40% silt. This textural class is ideal for faba bean production. The soil pH was moderately acidic according to the rating provided by Tekalign [22]. “Moreover, faba bean grows best in soils with pH values ranging from 6.5 to 9.0” [23]. However, the results indicated that the soil pH was below the optimum range (6.5 to 9.0) for faba bean production, which is one of the major factors responsible for reducing the crop's grain yield.

According to the rating provided by Cottenie [24], “the available phosphorus content of the experimental site was medium. Thus, the application of P fertilizer is required for improving faba bean yield in the study area”. Total nitrogen and organic matter of the soil was medium according to the rating of Tekalign [22] and Birhanu [25]. Hence, amending the soil with organic fertilizers is important for enhancing soil fertility to increase crop yields. “This indicates the ability of the soil to supply organic carbon and mineralizable nitrogen and mineralizable nitrogen for the proliferation of soil biota, which is important for soil biochemical processes that increase the mobility of nutrients, such as P and others, for plant uptake” (Gourley, 1999). The CEC of the soil was medium according to the rating of Hazelton and Murphy [23]. This value lies in the moderate range (12-25cmol/kg), which means the soil, is satisfactory for agricultural production (Table 1). Therefore, the soil of the experimental site is ideal for faba bean production except for its limitation in the availability of phosphorus, total nitrogen, and organic carbon.

3.2 After Harvesting Soil Chemical Properties

The average soil pH after harvesting was 5.67 indicating that moderately acidic reaction, which is not satisfactory for productive soils [26]. The average organic matter content and total nitrogen of the soil after harvest were 4.15 and 0.21, respectively (Table 2). The results indicated that the nitrogen and organic matter contents decreased numerically when compared to before sowing but described as medium according to the rating provided by Tekalign [22] and Birhanu [25]. The available phosphorus content of the experimental area after harvest was 6.67ppm, which indicates a decrease from medium to low level according to the rating of Cottenie [24]. In decreased available phosphorus, organic matter, and total nitrogen in the soil compared to before sowing showed that due to the uptake of Faba bean plant from the soil.

3.3 Analysis of Variance

The analysis of variance indicated that both the main effect and the interaction effects of NPS rate and inter-row spacing significantly influenced the Phenological and growth parameters of faba bean. The results showed that the main effect of the NPS rate and inter-row spacing significant ($P < 0.01$) difference on grain and dry biomass yield. Similarly, the main effect of NPS rate significantly ($P < 0.05$) influenced plant height. On the other hand, the interaction effect of NPS rate and inter-row spacing did not significantly affect the grain yield and dry biomass yield. However, the result revealed that the main effect of inter-row spacing and the interaction effect were significantly ($P < 0.01$) influenced number of pod per plant, number of seed per plant and hundred seed weight, whereas, the main effect of NPS rate did not influence these parameters. On other hand, the interaction effect significantly ($P < 0.01$) influenced days to maturity, whereas, the main effects of NPS rate and inter-row spacing did not significantly ($P < 0.05$) influenced days to maturity of faba bean.

Table 1. Soil physico-chemical properties of the study site in Degam district

No.	Soil properties	Value	Rating	Reference
1	pH (1 : 2.5 H_2O)	5.65	Moderate	London (1991)
2	Available P (ppm)	12.25	Medium	Cottenie [24]
3	Total N (%)	0.23	Medium	Tekalign [22] and Birhanu [25]
4	Organic matter (%)	4.57	Medium	Tekalign [22] and Birhanu [25]
5	CEC (cmol(+)·kg^{-1})	23.96	Medium	Hazelton and Murphy [23]
6	Clay (%)	18	-	-
7	Silt (%)	40	-	-
8	Sand (%)	42	-	-
9	Textural class	Loam	-	-

Table 2. Soil chemical properties of the study site in Degam district

Treatments	pH (1:2.5H_2O)	Av.p (ppm)	TN (%)	OM (%)
0kg NPS/ha with d/t IRS (30, 40, 50,60)	5.69	6.77	0.21	4.09
50kg NPS/ha with d/t IRS (30, 40, 50,60)	5.67	6.16	0.22	3.98
100kg NPS/ha with d/t IRS (30, 40, 50,60)	5.71	6.23	0.22	4.34
150kg NPS/ha with d/t IRS (30, 40, 50,60)	5.60	7.49	0.21	4.17
Mean	5.67	6.67	0.21	4.15

Table 3. Mean squares of ANOVA for phenological, growth, yield and yield components of faba bean as influenced by NPS rates and inter-row spacing

SV	DF	FD	DM	NPT	PH	NPP	NSP	HSW	DBMY	GY	HI
Rep	2	0.542	32.156	0.0358	2175.89	51.48	545.3	363.08	2.90E+07	5272165	23.32
NPS	3	15.455	2.983	0.4873	304.78**	58.81	370.1	13.67	2.80E+06**	2032994**	106.6
IRS	3	1.038	3.705	0.6365*	74.11	191.05**	1390.1**	363.75**	2.18E+06**	4035227**	33.73
Y	1	2784.260**	2007.510**	1.8463*	26357.13**	14065.28**	99997.0**	13024.70**	9.673E+08**	214523767**	7.19
NPS x IRS	9	7.853	11.909**	0.1927	53.16	81.75**	632.2*	50.76*	1.53E+06	617901	98.45
NPS x Y	3	17.427*	0.288	0.9265*	209.32*	33.68	281.3	8.58	1.950E+06	664321	69.75
SP x Y	3	3.622	0.399	0.1513	130.52	84.43*	777.5*	197.26	1.029E+07**	1489249.*	52.62
NPS x SP xY	9	7.122	0.288	0.2039	45.49	72.12*	579.5*	52.97	1.922E+06	269711.	123.55*
Residual	62	5.714	4.027	0.2153	67.01	26.55	259.5	77.18	1.68E+06	481246	49.08

*SV= Source of variation, DF= Degree of freedom, **= Significant at p=0.01 *= Significant at p=0.05, Y= Year, DF = Days to flowering; DM=days to maturity; NPT=; number of tiller per plant; NSP= number of seed per plant; PH= plant height; TSW= 1000-seed weight; GY= grain yield kg per hector; DBMY=Dry biomass ton per hector yield, HI=Harvest index (%); IRS= Inter-row spacing*

3.4 Phenological and Growth Parameters

3.4.1 Days to 50% flowering

The analysis of variance showed that neither the main effects nor the interaction effects of NPS rate and inter-row spacing had significantly ($P < 0.05$) influenced days to flowering of faba bean (Table 3).

3.4.2 Days to 90% physiological maturity

The results revealed that significant variations were found among the different rates of NPS fertilizer and inter-row spacing on the number of days to 90% physiological maturity. The highest number of days required for the completion of the growth period of faba bean (135.2 days) was recorded due to the application of 50kg NPS ha^{-1} with 40cm inter-row spacing while the shortest growth period of physiological maturity (131.2 days) was recorded due to application of 150kg NPS ha^{-1} with 50cm inter-row spacing (Table 4). The results indicated that faba bean plants that received 50kg NPS ha^{-1} with 40cm inter-row spacing required 3% more duration to reach 90% physiological maturity than 150kg NPS ha^{-1} with 50cm inter-row spacing plots. However, the application of 150kg NPS ha^{-1} with 50cm inter-row spacing treatment led the faba bean plants to earlier attainment of 90% physiological maturity as compared to the rest treatments. This might be the effects of phosphorus fertilization and wider inter-row spacing enhanced the physiological maturity of plants. Similar to the present results, Gemechu and Solomon [27] who reported that "application of phosphorus speed up crop physiological maturity and reduce the number of days to physiological maturity by controlling some key enzyme reactions that involve in hastening crop maturity". "In line with this result, closer row and plant spacing increased maturity days of safflower" [27].

3.4.3 Number of primary tillers per plant

The result revealed that the main effect of inter-row spacing significantly ($P < 0.05$) influenced the number of primary tillers per plant (Table 3). The highest number of primary tillers per plant (2.18) was recorded at a wider inter-row spacing of 60cm and the lowest number of primary tillers per plant (1.86) was recorded at a narrower inter-row spacing of 30cm of faba bean. The results indicated that the number of primary tillers increased as the number of inter-row spacing increased (Table 5). Increasing the inter-row spacing from 30cm to 60cm increased the number of primary tillers per plant by 17.2%. This is due to the fact that, as space among plants increases ample resources become available for each plant enhances the lateral vegetative growth of the crop. This result was in line with the findings of Mehmet [28] who reported that "increased number of primary tillers due to wider plant spacing for soybeans which may have resulted in the production of more assimilate for partitioning towards the development of more tillers". Similarly, Khalil, et al. [29] and Yucel [30] also reported "there was a trend that the number of primary tillers was increased as the space among plants increased compared to plants at narrow spacing".

3.4.4 Plant height

The analysis of variance indicated that highly significant ($P<0.01$) difference due to main effects of NPS rate on plant height (Table 3). The results revealed that increasing the rate of NPS from nil to 150 $kgha^{-1}$ increased plant height significantly. Thus, the tallest plants (104.6cm) were produced in response to the highest (150 $kgha^{-1}$) NPS rate followed by 100$kgha^{-1}$NPS rate. However, plants growing on the control and 50 $kgha^{-1}$ NPS rate produced plants with significantly lower mean values that were comparable (Table 5). The additional percentage increases in plant height in response to the application of 150 $kgha^{-1}$ NPS rate compared to unfertilized and 50 $kgha^{-1}$ NPS rates were 7.3 and 8.1%, respectively. "The increase in plant height in response to the increased P in blended NPS application rate indicates higher vegetative growth of the plants under higher P availability. The results stated that the plant height of faba bean was significantly influenced by P application compared to control plots" [31]. Dejene et al. [32] also reported that "phosphorus has significantly increased plant height at the application of 30 kg ha^{-1} P on common bean".

3.5 Yield Components and Yield of Faba Bean

3.5.1 Number of pods per plant

The results showed that the highest number of pods per plant (32) was recorded by the interaction of 100 $kgha^{-1}$ NPS rate with 50cm inter-row spacing followed by 100 $kgha^{-1}$ NPS rate with 60cm inter-row spacing (30) where as the lowest (16) was recorded by 100 $kgha^{-1}$NPS rate with 40cm inter-row spacing (Table 6). The increment in number of pods per plant at interactions of 100 kgha^{-1}NPS rate with the widest inter-row spacing (50cm and 60cm) might be due to an increase in net assimilation rate and reduction of competition in wider spacing. Thus, P fertilizer found in NPS fertilizer promotes the formation of nodes and pods in legumes and at wider spacing, the growth factors (nutrient, moisture, and light) for individual plants might be easily accessible that retained more flowers and supported the development of pods. The result is agreed with Meleta and Dergie [33] who reported that "increasing application rates of blended NPS fertilizer from 0 to 150kg ha^{-1} resulted in progressive increase of the number of pods per plant". This result was in line with Gemechu and Solomon [27] who reported that Number of pods per plant increased with decreasing plant density.

3.5.2 Number of seeds per plant

The interaction effect of inter-row spacing and NPS fertilizer rates significantly ($P < 0.01$) influenced the number of seeds per pod (Table 3). The highest number of seeds per plant (79.9) was recorded by the interaction of 100 kgha^{-1} NPS rate with 50cm inter-row spacing followed by 100 kgha^{-1} NPS rate with 60cm inter-row spacing (79.8) and the least (16) number seed per plant was recorded by 100 kgha^{-1}NPS rate with 40cm inter-row spacing (Table 6). The highest number of seeds per plant at the highest rate of NPS with wider inter-row spacing may be due to the positive role of P in photosynthetic materials production and allocation and its transfer to reproduction organs of the crop. The result is agreed with Hailu et al*.* [10] who reported that "the significantly highest number of seeds per plant was obtained at the highest rate of phosphorus application while the lowest was recorded from the control treatment". "Similarly, the highest number of seeds per plant was obtained from the wider-spaced plants compared to close-spaced plants in common bean" [34].

3.5.3 Hundred seed weight

The main effect of inter-row spacing showed a highly significant ($P < 0.01$) difference in hundred seed weight, whereas, the main effect of NPS rate and the interaction effect did not significantly influence of faba bean (Table 3). The highest hundred seed weight (60g) was recorded at the inter-row spacing of 30cm followed by at 50cm inter row- spacing and the lowest hundred seed weight was recorded at 60cm inter-row spacing but no significant difference in 100 seed weight existed between 40 and 50cm inter-row spacing (Table 7). The results showed that hundred seed weight was significantly decreased as inter-row spacing increased. In line with this result, Gemechu and Solomon [27] reported that hundred seed weight of Faba bean decreased with an increase in plant density. Similarly, hundred seed weight of haricot bean decreased with an increase in plant density [35].

3.5.4 Above ground dry biomass yield

The analysis of variance revealed that the main effect of inter-row spacing was a highly significant (P<0.0l) difference in above ground biomass yield. However, the main effect of the NPS rate and the interaction effect did not affect this parameter (Table 3). The result showed that significantly, the highest (6.73 t ha^{-1}) above-ground dry biomass yield was recorded at an inter-row spacing of 30cm followed by 40cm but there was no significant difference with that of 30cm, and the lowest (4.55 t ha^{-1}) was recorded at inter-row spacing of 60cm (Table 7). "The result revealed that increased inter-row spacing from 30cm to 60cm decreases above ground dry biomass yield. In line with this, lower plant densities resulted in a greater aboveground dry biomass" [36]. Hailu et al*.* [10] who reported that "above ground dry biomass yield ha^{-1} was significantly increased with decreasing plant spacing on soybean due to increased dry matter accumulation in densely populated crops".

Table 4. Interaction effects of NPS rates and intra-row spacing on days to maturity

	Inter-row spacing (IRS)			
NPS rate	**30**	**40**	**50**	**60**
0	131.8^{ab}	133.8^{bc}	134.3^{c}	133.2^{abc}
50	134.0^{bc}	135.2^{c}	134.5^{c}	132.0^{ab}
100	133.7^{bc}	133.2^{abc}	135.0^{c}	134.5^{c}
150	134.7^{c}	134.8^{c}	131.2^{a}	133.7^{bc}
Mean	133.72			
LSD (5%)	2.32			
CV (%)	1.5			

Table 5. Main effects of NPS rates and inter-row spacing on days to flowering, plant height, and number of primary tiller per plant

Treatments	Days to flowering	Plant Height (cm)	Number of Primary Tiller
NPS rate			
0	61.96	97.5^{b}	1.9
50	61.42	96.8^{b}	1.9
100	61.75	101.1^{ab}	2.1
150	60.17	104.6^{a}	2.1
Mean	61.32	100	2.03
LSD (5%)	NS	4.724	NS
Inter-row spacing			
30	61.54	101.14	1.86^{b}
40	61.33	100.99	1.93^{ab}
50	61.04	100.50	2.16^{a}
60	61.38	97.40	2.18^{a}
Mean	61.32	100	2.03
LSD (5%)	NS	NS	0.27
CV (%)	3.9	8.2	22.8

Table 6. Interaction effects of NPS rates and intra-row spacing on the number of seeds per plant and umber pod per plant

	Inter-row spacing(IRS)							
	Number of seeds per plant				Number of pod per plant			
NPS rate	30	40	50	60	30	40	50	60
0	51.2^{cd}	50.3^{cd}	56.6^{bcd}	59.4^{bc}	19.4^{cd}	20.2^{cd}	21.7^{bcd}	23.9^{bc}
50	52.5^{cd}	58.3^{bcd}	57.1^{bcd}	54.2^{cd}	21.4^{cd}	23.9^{bc}	22.7^{bc}	22^{bc}
100	48^{cd}	40.1^{d}	79.9^{a}	79.8^{a}	20.9^{cd}	15.9^{d}	32^{a}	30.8^{a}
150	59.6^{bc}	55.8^{cd}	55.3^{cd}	74.9^{ab}	23.1^{bc}	21.2^{cd}	23.67^{bc}	27.5^{ab}
Mean	58.3				23.15			
LSD (5%)	18.6				5.95			
CV (%)	27.6				22.3			

3.5.5 Grain yield

The main effect of NPS rate and inter-row spacing was highly significant (P<0.01) on grain yield. However, the interaction effect of the two treatments did not affect the grain yield of faba bean (Table 3). The maximum grain yield (3017 kg ha^{-1}) was recorded at the rate of 100 kg ha^{-1} NPS followed by 2789 kg ha^{-1} at the rate of 150 kg NPS ha^{-1} which was statistically at par while the lowest yield (2322 kg ha^{-1}) was recorded at nil application of NPS rate. These results depicted that increasing the rate of NPS from nil to 100 kg ha^{-1} significantly increased grain yield by 30%. However, increasing the rate of NPS from 100 to 150 kg ha^{-1} did not in increased grain yield. There was no significant change with the application of 50, 100, and 150 kg ha^{-1} NPS rate whereas significantly high variation was noticed for application of nil to 100 kg NPS rate. This means that the highest grain yield of faba bean was obtained at the rate of 100 kg ha^{-1} and increasing the rate of the fertilizer beyond this level has no grain yield advantage (Table 7). The result might be attributed to the fact that applying P fertilizer increases crop growth due to the translocation of photo assimilates from vegetative biomass to grains and yield on soils that are naturally low in P and in soils that have been depleted. The present finding was supported by the work of Tekle et al*.* [37] who reported that "the significantly highest grain yield was recorded at the highest rate of P application rate of 46 kg P_2O_5ha^{-1}as compared to 23 kgP_2O_5ha^{-1} rate and control treatments in faba bean".

Similarly, Hailu et al*.* [10] reported that Phosphorus application rate was significantly increased grain yield. However, the main effect of inter-row spacing influenced grain yield of faba bean. The highest grain yield (3143 kg ha^{-1}) observed at inter-row spacing of 30cm followed by 40cm whereas, the lowest (2177 kg ha^{-1}) was observed at 60 inter-row spacing. However, the result revealed that as increased inter-row spacing from 30cm to 60cm decreasing grain yield while it was statistically at parity with that of inter-row spacing of 40cm. Decreased inter-row spacing implied high plant density, which is concomitantly equal to high yield with every successful pod formation per plant. However, the total yield per unit area depended not only on the performance of individual plant but also on the number of plants per unit area as confirmed in this study. In the same manner, Gemechu and Solomon [27] reported that "grain yield per unit area increased with closer intra and inter-row spacing". Meleta and Dergie [33] reported that "closer spacing proved better in grain yield of rice, nutrient use efficiency and uptake than the wider row spacing"

3.5.6 Harvest index

Neither the main effects nor the interaction effects of NPS rate and inter-row spacing had significantly (P < 0.05) influenced the harvest index of faba bean (Table 3).

Table 7. Main effects of NPS rates and inter-row spacing on yield components and yield of faba bean

Treatment s	HSW (g)	AGDBMY ($tonh^{-1}$)	GY (kgh^{-1})	HI (%)
NPS rate				
0	54.85	5.27	2322^{b}	46
50	55.46	5.55	2648^{ab}	47
100	53.75	6.09	3017^{a}	50
150	54.18	5.71	2789^{a}	50
Mean	54.56	5.65	2694	48.3
LSD (5%)	NS	NS	400	NS
Inter-row spacing				
30	59.91^{a}	6.73^{a}	3143^{a}	47
40	52.43^{b}	6.08^{ab}	2857^{ab}	48
50	54.84^{ab}	5.25^{bc}	2599^{b}	50
60	51.06^{b}	4.55^{c}	2177^{c}	47
Mean	54.56	5.65	2694	48.0
LSD (5%)	5.070	0.92	400	NS
CV (%)	16.1	22.9	25.7	14.6

HSW= hundred seed weight, AGDBMY= Above ground dry biomass yield, GY= Grain Yield, HI= harvest index

Table 8. The mean effects of NPS fertilizer application and inter-row spacing on the economic profitability of faba bean production at Degem district during 2021 and 2022 under rain-fed condition

IRS	NPS	ASR	PS	PF	LC	MGY	AGY	GB	TVC	NB	DA	MRR
30	0	185	5550	0	6000	2733	2459.7	93468.6	11550	81918.6		
30	50	185	5550	1073.25	6000	2896	2606.4	99043.2	12623.25	86419.95		419.4
30	100	185	5550	2146.5	6000	3080	2772	105336	13696.5	91639.5		486.3
30	150	185	5550	3219.75	6000	2966	2669.4	101437.2	14769.75	86667.45	D	
40	0	138	4140	0	5550	2590	2331	88578	9690	78888		
40	50	138	4140	1073.25	5550	2753	2477.7	94152.6	10763.25	83389.35		419.4
40	100	138	4140	2146.5	5550	2937	2643.3	100445.4	11836.5	88608.9		44.1
40	150	138	4140	3219.75	5550	2823	2540.7	96546.6	12909.75	83636.85	D	
50	0	111	3330	0	5250	2461	2214.9	84166.2	8580	75586.2		
50	50	111	3330	1073.25	5250	2624	2361.6	89740.8	9653.25	80087.55		419.4
50	100	111	3330	2146.5	5250	2808	2527.2	96033.6	10726.5	85307.1		486.3
50	150	111	3330	3219.75	5250	2694	2424.6	92134.8	11799.75	80335.05	D	
60	0	92	2760	0	4500	2250	2025	76950	7260	69690		
60	50	92	2760	1073.25	4500	2413	2171.7	82524.6	8333.25	74191.35		419.4
60	100	92	2760	2146.5	4500	2597	2337.3	88817.4	9406.5	79410.9		486.3
60	150	92	2760	3219.75	4500	2483	2234.7	84918.6	10479.75	74438.85	D	

IRS= Inter-row spacing, NPS= NPS fertilizer rate ($kgha^{-1}$), ASR= Amount of seed required ($kgha^{-1}$), PS= Price of seed at planting ($30ETBha^{-1}$), Price of fertilizer (ETB $kgha^{-1}$), LC= Labor cost, MGY= Mean Grain Yield ($kgha^{-1}$), AGY= Adjusted Grain yield ($kgha^{-1}$), TVC= Total cost that varied among treatments ($ETBha^{-1}$), GB= Gross benefit ($ETBha^{-1}$), NB= Net benefit ($ETBha^{-1}$), DA= Dominance Analysis, D= Dominated treatments, MRR=Marginal Rate of Return (%)

3.6 Partial Budget Analysis

The partial budget analysis for the means of the two treatments was assessed. The economic analysis revealed that the highest net benefit (91639.5 ETB ha^{-1}) was obtained from inter-row spacing of 30 cm and application of 100 kg ha^{-1} NPS rate with an acceptable marginal rate of return (486.3%) while the lowest net benefit (68190 ETB ha^{-1}) was obtained from wider inter-row spacing of 60 cm with no application fertilizer (Table 8).Therefore, the inter-row spacing of 30 cm and 100 kg ha^{-1} NPS rate was most productive for economical production of faba bean ''Welki variety'' and can be recommended for the study area. The result supported by Tekle et al. [37] who reported that the highest net benefits of faba bean were obtained at high plant density (44 plants/ m^2) with optimum fertilizer rate under vertisol. Gezahegn et al. [38],[39] also stated that 30 cm inter-row and 8 cm intra-row spacing (42 plants/m^2) gave the highest net benefit with a high benefit-cost ratio and a marginal rate of return (MRR) which was higher than the minimum rate of return (100%).

4. CONCLUSION AND RECOMMENDATIONS

The study demonstrated that the phenology, growth, yield, and yield components faba bean are significantly influenced by NPS fertilizer rates and inter-spacing. However, NPS had more profound effects in enhancing the growth response of the crop than inter-row spacing. Following the application of 100 kg NPS ha-1 fertilizer and 30 cm interrow spacing, the highest grain production was measured. Grain production increased 30% when the rate of NPS was raised from zero to 100 kg ha-1; no additional gains were seen after this point. This indicates that the faba bean's maximum grain output was reached at a rate of 100 kg ha-1, and that there is no benefit to raising the fertilizer rate above this point in terms of grain yield. The results also showed that, although grain yield was statistically equivalent to that of inter-row spacing of 40 cm, increased inter-row spacing from 30 to 60 cm reduced grain production. Though, this means, decreasing inter-row spacing implied high plant density, which is concomitantly, equal to high yield with every successful pod formation per plant. The application of 100 kg NPS ha-1 rate and 30 cm inter-row spacing produced a maximum net benefit of 91,639.5 ETB ha-1 with an acceptable marginal rate of return of 486.3%. This was an economically feasible rate and the best rate to use by the end-users in Faba bean production and similar agro-ecologies to the study area. As a result, management has concentrated on plant density and fertilizers that contain N and P. This research does, however, point to the necessity of balanced fertilization, which includes soil pH correction. It is recommended that more research be done in the interim to assess how applying lime, organic fertilizers, and mineral NPS together will improve soil health and productivity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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