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Original Research Article

Suitable Spacing and Phosphorus Application Rate for Shero-Type Field Pea (*Pisum sativum* L.) Production on Acidic Nitisols in the Central Highlands of Ethiopia

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Abstract: Field pea is among the leading pulse crops grown in the highlands of Ethiopia in area coverage and productivity, although its productivity is far below its potential due to several production constraints, including optimum fertilizer and spacing recommendations. A field experiment was conducted to refine and/or determine the economically optimum spacing and phosphorus level for Shero-type field pea production on Nitisols at Holeta in 2021 and 2022. A 2*2*3 complete factorial combination of intra-row spacing (5 and 10 cm), inter-row spacing (20 and 30 cm), and phosphorus fertilizer (0, 23, 46, 69, and 92 kg P2O5/ha) was laid out in a randomized complete block design with three replications. P2O5 fertilizer and intra-row spacing main effects showed significant ($p<0.05$) effects on most of the studied parameters, while inter-row spacing main effects showed significant ($p<0.05$) effects only on hundred seed weight. The agronomic efficiency of P was highest at 46 kg P2O5/ha followed by 69 kg P2O5/ha over the non-fertilizer-applied treatment. Depending on the ANOVA and economic analysis results, the use of 69 kg P2O5/ha in combination with 10 cm intra-row spacing and 30 cm inter-row spacing (with a matching seed rate of about 73 kg/ha) was found to be optimum for row planting of Shero-type field pea on nitisols in Wolmera district and similar areas.
Keywords: Agronomic efficiency, Economic analysis, Inter-row spacing, Intra-row spacing, Nitisols, Phosphorus, Shero-type field pea.

INTRODUCTION

Field pea (*Pisum sativum* L.) is the third most important pulse crop in Ethiopia, after faba bean and chickpea, in terms of total annual production (Mussa *et al.*, 2006, CSA, 2022), and is becoming the second most important in terms of area coverage (CSA, 2022). It covers about 220,194.82hectares of land following faba bean (about 520,551.70 hectares of land) (CSA, 2022). National productivity is estimated to be 1.73 tons per hectare (CSA, 2022). According to the data from Fact fish (Factfish, 2019), Ethiopia was ranked 8th among the top ten field pea-producing countries and has a world share of 2.2%. The production quantity has increased from 110,000 tons in 1961 to 361,196 tons in 2017, though the increment lacks consistency from year to year (Factfish, 2019). It is a source of food, feed, and cash for the producers and also plays a significant role in soil fertility restoration through biological nitrogen fixation (Mussa *et al.*, 2006). However, the productivity of field pea in Ethiopia is far below its potential, as reflected in the wide gaps in grain yields between smallholder farmers' and researchers' fields. This is due to several production constraints, including the biological limitations of the crop and biotic and abiotic stresses under farmers' conditions (Mussa *et al.*, 2006, Mandefro *et al.*, 2009). Among which, optimum plant density and a lack of optimum fertilizer recommendation are the most important cultural practices determining grain yield and other important agronomic attributes of the crop (Sangoi, 2000). Plant population and/or seed rate are also influenced by row width, crop species, soil and climatic variables, and crop use. In general, both genetic and environmental factors affect plant density (Shirtliffe *et al.*, 2007). Hence, maximizing economic returns within the constraints of a specific environment is a major research objective (Smitchger and Weeden, 2018), as the more favorable the environment, the higher will be the optimum population (Olle, 2018), and as the level of available soil nutrients increases, the need for fertilizer

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decreases. Hence, the management practices for growing crops are of prime importance, and among the various agronomical factors, optimum plant nutrient management, mainly adequate phosphorus fertilization, appears to be the most significant parameter for improving the seed yield of field pea (Kanchan *et al*., 2017).

In addition to other roles, phosphorus (P) is one of the most limiting nutrients for field pea because this legume crop requires significant inputs for nodule formation (Powers and Thavarajah, 2019). In field pea, genetic variation may also exist for phosphorus use efficiency (PUE), which would allow for the development of cultivars that are less dependent on P fertilizer input (Powers and Thavarajah, 2019, Daniel and Tefese, 2018). Based on this, different varieties have evolved that show great variation in yield and quality under different climatic conditions (Kanchan *et al*., 2017). In Ethiopia, two field pea types are known to exist. One is meant for "*Kik-wot*" (stew made from split seeds), and the other is meant for "*Shero-wot*" (stew made from powdered field pea seeds). Accordingly, the varieties have been grouped into "*Kik-type* and "*Shero-type*" based on their dish (preparation) but without sufficient information on their crop management needs (spacing and fertilizer rate) and nutritional quality. A review by Kanchan *et al.,* (2017) indicated that application of 60 and 80 kg P_2O_5/ha significantly increased the seed yield of field pea by 11.30 and 13.92% compared to 40 kg P_2O_5/ha and also significantly increased the number of pods per plant. Phosphorus increases photosynthetic and reproductive activity, and as a result, seed yield per hectare is increased. In addition, phosphorus application had a significant effect on the plant height, number of branches, root and shoot dry weight, number of nodes, seed and biomass yield, crude protein content, and phosphorus content of the seed. There was a linear increase in the root dry weight, crude protein, and phosphorus content of seed up to 90 kg P_2O_5/ha (Kanchan *et al.,* 2017, Amjad *et al.*, 2004). Similarly, while evaluating six field pea varieties, an economically optimum yield was obtained at a rate of 90 kg P_2O_5/ha using the Ageta-6 variety in India (Kanchan *et al.,* 2017), which is in line with genetic variation among field pea varieties for phosphorus use efficiency (PUE).

In Ethiopia, intra-row spacing of 5 cm, inter-row spacing of 20 cm and a seed rate of 150 kg/ha with the application of 50–100 kg/ha DAP fertilizer have been recommended for field pea production (EIAR 2007, Amare *et al*., 2018). On the other hand, Mandefro *et al*., (2009) and Amare *et al.*, (2018) suggested a broadcast seed rate of 75–150 kg/ha. In another experiment, the application of 23, 46, 92, and 138 kg P_2O_5/ha increased field pea grain yield by about 158, 217, 286 and 288%, as reported in EIAR (2007), and by about 30, 45, 67, and 61%, as reported in EARO (1997), using similar P_2O_5 rates, respectively, compared with the no fertilizer-applied plots. Similarly, Daniel and Tefese (2018) recommended 69 kg P_2O_5/ha in southern Ethiopia. Yayeh *et al*., (2014) obtained higher yields while using a 25 cm inter row with 15 cm intra-row spacing for large seeded field pea varieties and a 20 cm inter row with 5 cm intra-row spacing for small seeded field pea varieties in West Gojam, Ethiopia. However, some research results in Ethiopia and overseas show that the presently used recommendations may need refinement both for seed and P rate. Gemechu *et al.,* (2001) also suggested conducting site-specific fertilizer trials and making recommendations since field pea is very sensitive to environmental changes and the results of different experiments were inconsistent across the country. Hence, considering the development of field pea varieties meant for different purposes, this experiment was done to refine and/or determine the economically optimum spacing and phosphorus level for the production of Shero-type field pea on Nitisols.

MATERIALS AND METHODS

In this paper, the authors used similar writing styles and approaches to a manuscript written by both authors on *Kik-type* field pea that was published earlier (Mebrate and Abdisa, 2023), because both experiments were done in similar areas using similar treatment combinations and methodologies.

Description of the experimental site

The experiment was conducted in the West Shewa zone in the district of Wolmera Zuria in 2021 and 2022, from July to December. The experimental site is situated at an altitude of approximately 2400 m above sea level, 30 kilometers west of Addis Abeba, between 09°03′ N latitude and 38°30′ E longitude. The long-term average annual precipitation is 1100 mm, with 85% of that falling between June and September and the remaining 15% falling between January and May. Minimum and maximum air temperatures over the long-term average are 6.2°C and 22.1°C, respectively (Mebrate *et al*., 2021), and the dominant soil type is Eutric Nitisols in association with Chromic *Vertisols* in some areas (Mosissa and Taye, 2021). Mosissa and Taye (2021) also reported that the pH of experimental fields lies in the range of 4.05 to 4.78 and was found to be very strongly acidic, as rated by Murphy (1968). The organic carbon of the experimental fields lies in the range of 1.66 to 2.00%, which is classified as medium (Tadese, 1991). The total nitrogen percentage was in the range of 0.15 to 0.17% and was rated as moderate (Debele, 1980). The available soil phosphorous is in the range of 9.72 to 11.28 ppm, which is classified as medium (Cottenie, 1980).

Weather data collection

The daily base data on rainfall, maximum, and minimum temperature were recorded at the Holeta Research Center metrology station by employees of the center.

Treatments, experimental design, and procedures

The treatments included a factorial combination of two intra-row spacings (5 and 10 cm), two inter-row spacings (20 and 30 cm), and five P_2O_5 levels (0, 23, 46, 69, and 92 kg/ha). Hence, a 2 x 2 x 5 factorial experiment was conducted in a randomized complete block design (RCBD) with three replications. The recently released Shero-type field pea variety "*Bursa*" (EH05027-2) was used. The gross plot size of 9.0 m^2 (1.8 m wide and 5 m long) was used. The number of rows per plot for the 20 and 30cm inter-row spacing was 9 and 6, respectively, while all necessary data were taken from central rows of 7 and 4 rows in the 20 and 30 cm inter-row spacing, respectively, leaving one border row on each side. Space between replications and plots was maintained at 1 m and 0.6 m, respectively. TSP chemical fertilizer was used as a source of P_2O_5. Nitrogen at a rate of 18 kg/ha was applied uniformly to all experimental plots during sowing. Weeding and other cultural practices were undertaken as per the recommendation. Pests will be controlled by applying pesticides.

Crop data collection and analysis

Data on plant height, number of pods per plant, and number of seeds per pod were measured from 10 randomly selected plants from the central rows of each plot. Aboveground dry biomass was weighed using the sun-dried harvested plants in each net plot. Grain yield was measured from each net plot, while 100 seed weights were measured in grams for randomly picked 100 seed samples from the grain yield harvested in each net plot. The harvest index was calculated as a ratio of grain yield to aboveground dry biomass.

Data were subjected to the analysis of variance (ANOVA) following the statistical procedure for three-factor factorial experiments using SAS Software version 9.0 (SAS, 2002). A mean comparison was performed using Duncan's Multiple Range Test (DMRT) at a 5% level of significance upon obtaining significant F-values for the main effects and interactions. Two years' data were combined if the variance was found to be homogeneous, which was tested by employing Bartlett's test.

Economic analysis was performed following the partial budget analysis method of CIMMYT (1988). Accordingly, the price of the grain yield of the Shero-type field pea variety "Bursa" was 55 Ethiopian Birr (ETB) per kg, while the phosphate (P_2O_5) fertilizer price was 34.00 ETB per kg. The variable costs included the cost of seed during sowing (June) and were estimated at 60.00 ETB per kg. The average yield was adjusted downward to 10%, assuming a 10% yield reduction if farmers managed the same on a larger plot. In order to use the marginal rate of return (MRR) as a basis for fertilizer and spacing recommendations, the minimum acceptable rate of return was set at 100% (CIMMYT, 1988). A treatment having a higher total cost that varies and a lower net benefit than the immediately preceding treatment with a lower total cost that varies and a higher net benefit was considered to be dominated and was eliminated from further analysis.

RESULTS AND DISCUSSION

Weather conditions for the crop growth period

According to the unpublished data of the Holeta Climate, Geospatial, and Biometrics Research Directorate (Figure 1), rainfall showed an unpredictable pattern from year to year. For example, in 2022, a higher amount of rainfall was recorded from June to August than in 2021 and the thirty-year average (1969 to 2020). On the other hand, in 2021, a higher amount of rainfall was recorded from September to October than in 2022 and the thirty-year average (1969 to 2020). Similarly, a higher amount of rainfall was recorded from November to December for the thirty-year average than for the years 2021 and 2022. However, there was a fair distribution of rainfall throughout the growth period (June to December) for the thirty-year average and the year 2022 compared to the year 2021. Maximum temperatures showed an increasing trend from the last thirty years to 2022. However, it showed a cross-over trend between the years 2021 and 2022. Accordingly, it was higher for the year 2022 from June to October than the year 2021 and lower from November to December than the year 2021 (Figure 1). On the other hand, the mean minimum temperature showed a decreasing trend from July to December for the thirty-year period, whereas it showed an inconsistent trend for the years 2021 and 2022. However, the highest mean minimum temperature was recorded for the year 2022 (with the exception of October and November) when compared with the year 2021 (Figure 1).

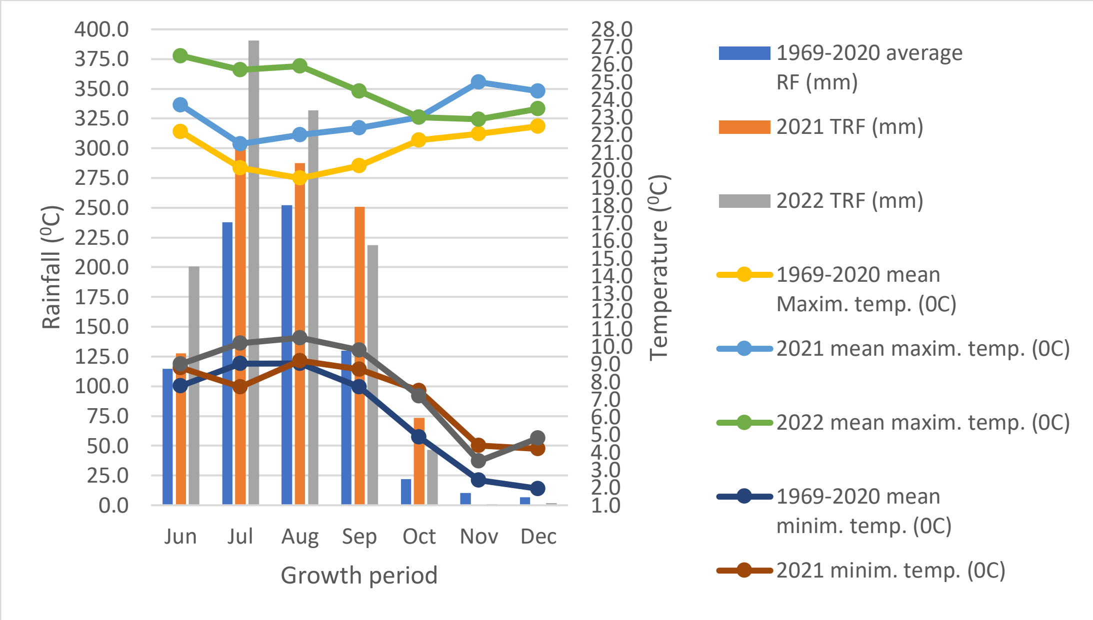

Fig 1: Thirty-year (1969–2020) average, the years 2021 and 2022 monthly rainfall, maximum and minimum temperatures of the Shero-type field pea growing period at Holeta

Source: Holeta Climate, Geospatial, and Biometrics Research Directorate (unpublished data)

Yield related parameters, yield components, and yield

The results of the combined analysis of variance over years (2021 and 2022) of growth parameters, yield components, and yield of Shero-type field pea as affected by spacing and P_2O_5 fertilizer are presented in Table 1. Year and P_2O_5 fertilizer had more significant main effects than intra- and inter-row spacing on Plh, BM, GY, and HI of Shero-type field pea (Table 1), while their effects were more or less comparable on NPPP, NSPP, and HSW (Table 1). The two-way, three-way, and four-way interactions significantly affected grain yield more than growth parameters and yield components (Table 1).

The year effect was significant on plant height, biological yield, grain yield, and harvest index (Table 2). The tallest plant (184.5 cm high) was obtained from the first year, while the highest biological yield (8.47 t/ha), the highest grain yield (2.89 t/ha), and the highest harvest index (0.34) were obtained from the second year (Table 2). Prusinski and Borowska (2022) indicated that one of the reasons for legume yield instability is varied across-year precipitation and precipitation distribution. Accordingly, as depicted in Fig. 1, the highest biological and grain yields were obtained in the second year, where there was a higher and more fair distribution of rainfall throughout the growth period (June to December) for the year 2022 than the year 2021.

Table 1: Mean squares of ANOVA for some growth parameters, yield components, and yield of Shero-type field pea at Holeta, combined over years

Source	Plh (cm)	NPPP	NSPP	HSW (g)	BY (t/ha)	GY (t/ha)	HI
Year (Yr)	1369.576**	3.502^{ns}	1.008^{ns}	0.290^{ns}	195.713**	41.937**	0.077**
P_2O_5	681.592**	19.017*	0.579^{ns}	0.304^{ns}	36.575**	2.432**	0.006**
Intra-row spacing (Intra)	541.875^{ns}	22.447*	0.867^{ns}	5.941*	0.246^{ns}	0.383*	0.017**
Inter-row spacing (Inter)	102.675^{ns}	4.840^{ns}	0.056^{ns}	8.802**	0.004^{ns}	0.115^{ns}	0.003^{ns}
Yr* P_2O_5	125.425^{ns}	5.519^{ns}	1.003^{ns}	1.354^{ns}	1.434^{ns}	0.369**	0.0015^{ns}
Yr*Intra	35.208^{ns}	16.950^{ns}	0.192^{ns}	2.002^{ns}	0.212^{ns}	0.552**	0.009**
Yr*Inter	460.208^{ns}	0.0007^{ns}	0.048^{ns}	0.004^{ns}	0.673^{ns}	0.215^{ns}	0.002^{ns}
P_2O_5*Intra	250.601^{ns}	4.562^{ns}	0.516^{ns}	0.885^{ns}	1.489*	0.239**	0.0002^{ns}
P_2O_5*Inter	170.301^{ns}	9.718^{ns}	0.319^{ns}	1.833^{ns}	2.151**	0.115^{ns}	0.002^{ns}
Intra*Inter	22.016^{ns}	5.419^{ns}	0.432^{ns}	3.502^{ns}	0.747^{ns}	0.446**	0.003^{ns}
P_2O_5*Intra*Inter	264.165^{ns}	20.753**	0.063^{ns}	0.797^{ns}	0.324^{ns}	0.030^{ns}	0.0009^{ns}
Yr* P_2O_5*Intra*Inter	279.714^{ns}	8.857^{ns}	0.288^{ns}	1.423^{ns}	0.504^{ns}	0.154**	0.001^{ns}
Error	172.1250	5.5553	0.4264	1.0745	0.5949	0.0574	0.0013

Note: Plh=Plant height; NPPP=Number of pods per plant; NSPP=Number of seeds per pod; HSW=Hundred seeds weight; BY=Biological yield; GY=Grain yield; HI=Harvest index; ns = not significant at 5%.

Table 2: Main effects of P_2O_5 fertilizer on some growth parameters, yield components, and yield of Shero-type field pea at Holeta, combined over years

Year	Plh (cm)	NPPP	NSPP	HSW (g)	BY (t/ha)	GY (t/ha)	HI
2021	184.5[a]	10.4	4.6	19.55	5.91[b]	1.71[b]	0.29[b]
2022	177.7[b]	10.0	4.4	19.65	8.47[a]	2.89[a]	0.34[a]
Significance	**	ns	ns	ns	**	**	**

Note: Plh=Plant height; NPPP=Number of pods per plant; NSPP=Number of seeds per pod; HSW=Hundred seeds weight; BY=Biological yield; GY=Grain yield; HI=Harvest index; ns = not significant at 5%.

Effect of P_2O_5 fertilizer

As indicated in Table 3, the main effect of P_2O_5 fertilizer showed a significant effect on all parameters considered with the exception of the number of seeds per pod and the hundred seed weight of field pea. Accordingly, plant height increased by 7.47% as P_2O_5 fertilizer increased from 0 to 92 kg/ha (Table 3), which might be attributed to the positive influence of phosphorus application on root elongation that might have promoted the growth of the plant as indicated in plant height (Kanchan *et al*., 2017). In line with this result, Kanchan *et al*., (2017) reported maximum plant height under application of the highest P level (120 kg P_2O_5/ha) at all the growth stages of field pea. Similarly, Yadav and Dhanai (2017) also reported the tallest plants under the highest phosphorus level of 90 kg P_2O_5/ha.

The highest number of pods per plant (11.1) was obtained from the highest P_2O_5 fertilizer level of 69 kg/ha (Table 3). An increase in the number of pods per plant with the application of phosphorus might have resulted from more prominent growth of the plant, which in turn enhanced the number of pods per plant (Khan *et al*., 2021). Kanchan *et al*., (2017), Yadav and Dhanai (2017) and Similarly, Akhtar *et al*., (2003), Daniel and Tefese (2018), and Khan *et al*., (2021) obtained the highest number of pods from the highest dose of phosphorus (69, 90, 120, 69, and 90 kg P_2O_5 kg/ha, respectively). The successive increase in the number of pods per plant under varied doses of phosphorus may be due to variations in the availability of more nutrients for the proper growth of plants at different stages of the crop (Yadav and Dhanai, 2017).

As P_2O_5 fertilizer increased from 0 to 92 kg/ha, biological yield increased by 56.18%, producing 8.52 t/ha at the P_2O_5 level of 92 kg/ha, and the differences in the biological yield under all five doses of phosphorus were significant from each other (Table 3). In accordance with the present experiment, Yadav and Dhanai (2017) and Daniel and Tefese (2018) reported significant increases in field pea biological yield as phosphorus increased in doses from 0 to 90 kg P_2O_5/ha and 0 to 69 kg P_2O_5/ha, respectively. As reported by Husain *et al*., (2019), phosphorus has an enhancing impact on plant growth and biological yield through its importance as energy storage and the transfer of energy necessary for metabolic processes.

Grain yield increased by 38.17% as P_2O_5 fertilizer increased from 0 to 92 kg/ha, and the highest rate of phosphorus application (92 kg P_2O_5/ha) resulted in the maximum grain yield (2.57 t/ha) (Table 3). However, there was no significant difference between the three phosphorus levels (46, 69, and 92 kg/ha) that might be confirmed with the economic analysis. In field pea, increased grain yield with the application of phosphorus has also been reported by various workers. For example, the application of 23, 46, 92, and 138 kg P_2O_5/ha increased field pea grain yield by about 158, 217, 286 and 288%, as reported in EIAR (1996), and by about 30, 45, 67, and 61%, as reported in EARO (1997), respectively, compared with the no fertilizer-applied plots. Similarly, Getachew *et al*., (2006) obtained the highest and most profitable yield of field pea from the application of 27:30 kg N/P/ha. Kanchan *et al*., (2017), Amjad *et al*., (2004), Yadav and Dhanai (2017) and Khan *et al*., (2021) also observed a significant increase in seed yield with an increase in the dose of phosphorus from 0 to 69, 0 to 90, 60 to 120, and 0 to 90 kg P_2O_5/ha, respectively. According to Makasheva (1983), yield is determined by the interaction of many inherent characters with soil, climate, and agronomic conditions. For grain yield, the highest (29.38 kg/kg) agronomic efficiency of P (AEp) was obtained at the P_2O_5 rate of 46 kg/ha, followed by the P_2O_5 rate of 69 kg/ha (22.58 kg/kg) over the non-fertilizer-applied treatment (Table 3) and showed a decreasing trend as the P_2O_5 level increased from 46 to 92 kg P_2O_5/ha (Fig. 2). In line with this result, Bekele (2022) reported the highest AEp from the lowest P rate of 23 kg/ha and the lowest AEp from the highest P rate of 115 kg/ha in maize.

On the other hand, the harvest index decreased by 13.33% as P_2O_5 fertilizer increased from 0 to 92 kg/ha (Table 3). The results of the present investigation revealed that P and the harvest index were inversely related to each other. Contrary to our results, Kanchan *et al.*, (2017), Daniel and Tefese (2018) and Amjad *et al*., (2004) obtained the highest harvest index under the highest phosphorus level of 90, 120, and 69 kg P_2O_5/ha, respectively.

Table 3: Main effects of P_2O_5 fertilizer on some growth parameters, yield components, and Yield of Shero-type field pea at Holeta, combined over years

P2O5 kg/ha	Plh (cm)	NPPP	NSPP	HSW (g)	BY (t/ha)	GY (t/ha)	HI	AE_p (kg/kg)
0	173.9^c	8.7^b	4.4	19.58	5.44^e	1.86^c	0.34^a	-
23	177.7^{bc}	10.4^a	4.3	19.72	6.47^d	2.07^b	0.32^{bc}	20.92
46	184.9^{ab}	10.1^a	4.5	19.44	7.53^c	2.45^a	0.32^{bc}	29.38
69	182.1^{ab}	11.1^a	4.5	19.58	7.99^b	2.54^a	0.32^{bc}	22.58
92	186.9^a	10.7^a	4.7	19.69	8.52^a	2.57^a	0.30^c	17.68
Significance	**	*	ns	ns	**	**	**	
CV (%)	7.24	23.07	14.52	5.29	10.72	10.42	11.22	

Note: Plh=Plant height; NPPP=Number of pods per plant; NSPP=Number of seeds per pod; HSW=Hundred seeds weight; BY=Biological yield; GY=Grain yield; HI=Harvest index**;** AE=Agronomic efficiency of P on grain yield

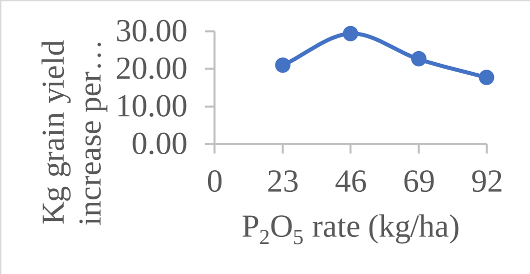

Fig 2: Agronomic efficiency of applied P on Shero-type field pea grain yield

Effect of intra-row-and inter-row spacing

As indicated in Table 4, the main effect of intra-row spacing showed a significant effect on number of pods per plant, hundred seed weight, grain yield, and harvest index but had no significant effect on number of seeds per pod or biological yield. Accordingly, significantly the highest number of pods per plant (10.6), hundred seed weight (19.83 g), grain yield (2.36 t/ha), and harvest index (0.33%) were obtained from the wider intra-row spacing of 10 cm. The reduction in the number of pods per plant, seeds per pod, and seed weight at higher densities might be due to increased interplant competition (Türk *et al*., 2011). In line with this result, Asaye *et al*., (2018) obtained the significantly highest harvest index from the wider intra-row spacing of 15 cm in mung bean. Contrary to our results, Yayeh *et al*., (2014) reported a non-significant difference between 5, 10, and 15 cm intra-row spacing on the number of pods per plant, thousand seed weight, and grain yield of field pea, as well as the presence of a significant difference on the plant height of field pea, while we reported a non-significant difference.

The main effect of inter-row spacing showed a significant effect only on hundred seed weight, and the highest (19.87 g) was obtained from the wider inter-row spacing of 30 cm (Table 4). In line with this result, Yayeh *et al*., (2014) reported a non-significant difference between 20 and 25 cm inter-row spacing on plant height, number of pods per plant, number of seeds per pod, and grain yield of field pea (except for the hundred or thousand seed weight, on which they reported a non-significant difference and we reported a significant difference). On the contrary, Prusinski and Borowska (2022) reported a significant difference between 16 and 32 cm inter-row spacing (with the highest intra-row spacing of 16 cm) for the number of pods per plant and number of seeds per pod.

Table 4: Main effects of intra-row- and inter-row spacing on some growth parameters, yield components, and yield of Shero-type field pea at Holeta, combined over years

Spacing	Plh (cm)	NPPP	NSPP	HSW (g)	BY (t/ha)	GY (t/ha)	HI
Intra-row spacing (cm)							
5	183.2	9.8^b	4.4	19.38^b	7.24	2.24^b	0.31^b
10	179.0	10.6^a	4.6	19.83^a	7.14	2.36^a	0.33^a
Significance	ns	*	ns	*	ns	*	**
Inter-row spacing (cm)							
20	182.0	10.0	4.5	19.33^b	7.20	2.27	0.31
30	180.2	10.4	4.5	19.87^a	7.18	2.33	0.32
Significance	ns	ns	ns	**	ns	ns	ns
CV (%)	7.24	23.07	14.52	5.29	10.72	10.42	11.22

Note: Plh =Plant height; NPPP=Number of pods per plant; NSPP=Number of seeds per pod; HSW=Hundred seeds weight; BY=Biomass yield; GY=Grain yield; HI=Harvest index

Interaction Effects

Three-way interaction effects of P_2O_5 fertilizer with intra-row spacing and inter-row spacing

The highest number of pods per plant (13.8) was obtained at a combination of 92 kg P_2O_5/ha with an intra-row spacing of 10 cm and an inter-row spacing of 30 cm (Table 5). To the knowledge of the authors, no similar three-way interaction reports were found on pulse crops to discuss our results in line with other findings.

Table 5: Three-way interaction effects of P_2O_5 fertilizer with intra-row spacing and inter-row spacing on number of pods per plant (NPPP) at Holeta, combined over years

P_2O_5 fertilizer (kg/ha)	Intra-row spacing (cm)	Inter-row spacing (cm)	NPPP
0	5	20	7.1eg
0	5	30	8.6c-g
0	10	20	10.6bcd
0	10	30	8.8c-g
23	5	20	10.3b-e
23	5	30	10.1b-g
23	10	20	9.9b-g
23	10	30	11.3a-d
46	5	20	10.0b-g
46	5	30	10.3b-f
46	10	20	10.3bcd
46	10	30	9.9b-g
69	5	20	10.7bcd
69	5	30	9.8b-g
69	10	20	12.3ab
69	10	30	11.6abc
92	5	20	11.0a-d
92	5	30	10.1b-g
92	10	20	8.0d-g
92	10	30	**13.8a**

Note: LSD = Least significant difference; CV= Coefficient of variation; the means of each parameter in column and row followed by the same letters are not significantly different at 5%.

Two-way interaction effect of P_2O_5 fertilizer with intra-row spacing

The highest biological yield (8.76 t/ha) was obtained at a combination of 92 kg P_2O_5/ha with an intra-row spacing of 5 cm, though not significantly different from the combination of 69 kg P_2O_5/ha with an intra-row spacing of 10 cm and the combination of 92 kg P_2O_5/ha with an intra-row spacing of 10 cm (Table 6). To the knowledge of the authors, no similar two-way interaction reports were found on pulse crops to discuss our results in line with other findings.

The highest grain yield (2.75 t/ha) was obtained at a combination of 69 kg P_2O_5/ha with an intra-row spacing of 10 cm, though not significantly different from a combination of 92 kg P_2O_5/ha with an intra-row spacing of 5 cm (Table 6). Mebrate *et al*., (2021) reported the highest grain yield for sweet lupine at the combination of 46 kg P_2O_5/ha with 7 cm intra-row spacing, though it was not significantly different from the combination of 23 kg P_2O_5/ha with an intra-row spacing of 7 cm.

Table 6: Two-way interaction effects of P_2O_5 fertilizer with intra-row spacing on biological- and grain yield (t/ha) at Holeta, combined over years

P_2O_5 fertilizer (kg/ha)	Biological yield (t/ha)		Grain yield (t/ha)	
	Intra-row spacing (cm)		Intra-row spacing (cm)	
	5	10	5	10
0	5.62e	5.26e	1.85e	1.86e
23	6.36d	6.59d	1.97e	2.17d
46	7.76bc	7.30c	2.43bc	2.47bc
69	7.68bc	8.31ab	2.34cd	2.75a
92	8.76a	8.27ab	2.62ab	2.53bc

Two-way interaction effect of P_2O_5 fertilizer with inter-row spacing

The highest grain yield (2.75 t/ha) was obtained at the combination of 92 kg P_2O_5/ha with an inter-row spacing of 30 cm, though it was not significantly different from four of the combinations (Table 7). Mebrate *et al*., (2021) reported a non-significant difference among treatments for the interaction between P_2O_5 and inter-row spacing levels in sweet lupine.

Table 7: Two-way interaction effects of P_2O_5 fertilizer with inter-row spacing on grain yield (t/ha) at Holeta, combined over years

P_2O_5 fertilizer (kg/ha)	Inter-row spacing (cm)	
	20	**30**
0	1.94cd	1.78d
23	2.04c	2.10c
46	2.43b	2.48ab
69	2.47ab	2.62ab
92	2.47ab	2.67a

Two-way interaction effect of intra-row spacing with inter-row spacing

The highest grain yield (2.75 t/ha), though significantly different only from the combination of intra-row spacing of 5 cm with inter-row spacing of 20 cm, was obtained at the combination of intra-row spacing of 10 cm with inter-row spacing of 20 cm (Table 8). In a similar experiment, La *et al*., (2022) reported higher field pea yield from a crop geometry of 30 cm x 10 cm. Asaye *et al*., (2018) noticed adverse effects on the yield of mung bean at a very high plant population (20 × 5 cm) that might be due to intense interplant competition and floral abortion. Contrary to our result, Yayeh *et al*., (2014) reported a non-significant effect of intra-row spacing (5, 10, and 15 cm) with inter-row spacing (20 and 25 cm) on the grain yield of field pea. In mung bean, based on agronomic performance and economic analysis, the use of a combination of 40 × 15 cm inter- and intra-row spacing was found to be promising (2018).

Table 8: Two-way interaction effects of intra-row spacing and inter-row spacing on grain yield (t/ha) at Holeta, combined over two years

Intra-row spacing (cm)	Inter-row spacing (cm)	
	20	**30**
5	2.15b	2.33a
10	2.39a	2.33a

Economic analysis

Since there was no three-way interaction between P_2O_5 fertilizer, intra-row spacing, and inter-row spacing for grain yield, economic analysis was performed using the two-way interaction of intra-row spacing with inter-row spacing and the main effect of P_2O_5 fertilizer based on the procedures indicated in CIMMYT (1988). Accordingly, for the main effect of P_2O_5 fertilizer, relatively the highest net benefits of 123384.00 ETB/ha with a marginal rate of return of 469.69% were obtained under a P_2O_5 fertilizer level of 69 kg/ha (Table 9). Similarly, for the interaction of intra-row spacing with inter-row spacing, the highest net benefits of 110958.20 ETB/ha with the lowest TVC value were obtained under the combination of 10 cm intra-row spacing with 30 cm inter-row spacing. Though the highest net benefit of 111673.42 ETB/ha was obtained under the combination of intra-row spacing of 10 cm with inter-row spacing of 20 cm, the MRR of 31.72% was below the minimum rate of return of 100% (Table 10).

In summary, based on ANOVA results, though none significant, the three-way combination of P_2O_5 fertilizer with intra-row spacing and inter-row spacing produced the highest grain yield at the combination of 69 kg P_2O_5/ha fertilizer with 10 cm intra-row spacing and 30 cm inter-row spacing (data not shown), which may support our final result that is going to be optimum (recommendation of 69 kg P_2O_5/ha in combination with 10 cm intra-row spacing and 30 cm inter-row spacing).

Table 9: Dominance and marginal rate of return analysis for grain yield (t/ha) of field pea as affected by P_2O_5 fertilizer level at Holeta, combined over years

P_2O_5 (kg/ha)	Observed grain yield (t/ha)	Adjusted grain yield (t/ha)	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
0	1.86	1.67	92070.00	0.00	92070.00	
23	2.07	1.86	102465.00	782.00	101683.00	1229.28
46	2.45	2.21	121275.00	1564.00	119711.00	2305.37
69	2.54	2.29	125730.00	2346.00	123384.00	469.69
92	2.57	2.31	127215.00	3128.00	124087.00	89.90

Note: GB = Gross benefit; TVC= Total variable cost; NB= Net benefit; MRR= Marginal rate of return; D= Dominated

Table 10: Dominance and marginal rate of return analysis for grain yield of field pea as affected by the interaction of intra- and inter-row spacing at Holeta, combined over years

Intra-*inter-row spacing combination (cm)	Seed rate (kg/ha)	Observed grain yield (t/ha)	Adjusted grain yield (t/ha)	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
10*30	72.95	2.33	2.10	115335	4376.84	110958.20	
10*20	110.53	2.39	2.15	118305	6631.58	111673.42	31.72
5*30	148.11	2.33	2.10	115335	8886.32	106448.68	
5*20	221.05	2.15	1.94	106425	13263.16	93161.84	

Note: GB= Gross benefit; TVC= Total variable cost; NB= Net benefit; MRR= Marginal rate of return; D= Dominated

CONCLUSIONS

Our study clearly indicates the role of proper spacing and fertilization levels in getting a higher and optimal yield in *Shero-type* field peas. The agronomic efficiency of P fertilizer was higher at the P2O5 rate of 46 kg/ha. Depending on the ANOVA and economic analysis results, the use of 69 kg P_2O_5/ha in combination with 10 cm intra-row spacing and 30 cm inter-row spacing (with a matching seed rate of about 73 kg/ha) was found to be optimum for row planting of Shero-type field pea on nitisols in Wolmera district and similar areas.

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