Determining of Phosphorus Fertilizer and Plant Population for Yield and Yield Attributes of Kik-Type Field Pea (Pisum sativum) in North West Ethiopia

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Abstract: *Field pea experiment having different intra-row and inter-row spacing as well as phosphorous fertilizer was conducted at Debre Markos Agricultural Research station in order to refine economically optimum plant spacing and phosphorus fertilizer level. A factorial combination of five P_2O_5 rates (0, 23, 46, 69 and 92 kg ha^{-1}), two intra-rows (5, 10 cm) and two inter-row (20, 30 cm) spacing was carried out using randomized complete block design with three replications. The results of the analysis of variance indicate that phosphorous fertilizer had a significant effect ($p<0.05$) on seed yield and yield attributes of field pea, the main effects of intra-row spacing and inter- row spacing had a significant effect ($p<0.05$) on number of pods per plant, seed and biological yield. The combination of 10 cm intra-row spacing and 30 cm inter-row spacing resulted in the highest seed yield for field pea. Additionally, the maximum seed yield (1942.39 kg ha^{-1}) and net benefit ETB 66,369.26 was observed at 92 P_2O_5 kg ha^{-1}. Hence, plating kik-type field pea with 10 cm intra-row and 30 cm inter-row spacing's with application of 92 P_2O_5 kg ha^{-1}is found to be economically feasible and recommended in Aneded district and similar agro ecologies.*

Keywords: Field pea, intra-row, inter-row, phosphorous fertilizer, seed yield

INTRODUCTION

Pulse crops are part of the smallholders' agricultural production in Ethiopia and are beneficial for economic advantage and as an alternative source of protein, cash income and food security (Birhanu *et al*., 2020). Field pea (Pisum sativum L.) is one of the major stable food grains and also low-input break legume crops grown in the highlands of Ethiopia (Yayeh *et al.*, 2015). It contains proteins, carbohydrates, vitamin A and C, calcium and phosphorous (Dawson, 2022). In addition, field pea contributes to soil fertility and serves as a rotation crop in a cereal-based cropping system (Mulusew *et al*., 2014). In 2021/2022, the area cultivated with field pea was 220,194.82 ha, and the production from this area was 0.38 million metric tons of highland pulses (ESS, 2022). Despite its paramount importance and large area coverage, the yield of field pea in Ethiopia is very low which is 1.73 t ha^{-1} (ESS, 2022). The major yield limiting factors in field pea production are phosphorous fertilizer and plant population.

Number of plants per unit area influenced plant size, yield components and ultimately the seed yield (Nuru and Kemila, 2021). Plant density is one of the agronomic practices that affects yield and yield related traits of legumes (Kissi and Tamiru, 2016). They argued that as the plant population is too high, plants compete for resources and yield was reduced; whereas if the population is too low, more growing space was wasted, and these in turn lower the yield.An experiment conducted on field pea using 5 and 10 cm intra-row spacing revealed that relatively better seed yield was obtained from 10 cm intra row spacing (Mebrate and Abdisa, 2023).

Phosphorus is an essential nutrient which has key role in plant growth and biological yield by its function as energy storage and provides energy for metabolic processes (Husain *et al*., 2019). It also affects crop growth and development and is directly related to root proliferation, straw strength, grain formation, maturation and quality. Because P is required for root growth and nodulation, its supply must be largely met by inorganic fertilizers (Bhat *et al*., 2013). Phosphorous availability limits more than 30% of the world's arable land (Mesfin *et al*. 2007). The yield of field pea was increased with increasing phosphorous fertilizer application (Mandloi*et al*., 2020). According to those authors application of phosphorous fertilizer 30 to 90 P_2O_5 $kgha^{-1}$ increase the seed yield of field pea by 37.18%. Beside to this, field pea experiment conducted using different levels of phosphorous fertilizer showed that seed yield of field pea increased with increasing phosphorous fertilizer (Mebrate and Abdisa, 2023). However, the response of phosphorus depends upon many factors like climate, variety and soil type and availability of nutrients during the period of growth (Mandloi*et al*., 2020).

In Ethiopia, varieties of Kik and Shero- type were cultivated for the preparations of kik- wot and shero- wot, respectively, but no information was found about plant and row spacing, optimum phosphorous fertilizer rate to grow these varieties. Even, some investigations done on plant density and phosphorous fertilizer for field pea showed in consistent results. A study on the effect of intra-row and inter-row spacing on yield and yield components of field pea showed that, planting field pea varieties using 20 cm inter-row and 10 cm intra-row spacing significantly increase seed yield (Yayeh*et al.,* 2015). In addition to this, a study conducted in the central highlands of Ethiopia showed that 30 cm inter-row and 10 cm intra-row spacing with 69 P2O5 kg ha^{-1} provided the highest yield of field pea (Mebrate and Abdisa, 2023). However, despite these facts, field pea growers in the study area are recommended to follow the blanket recommendation of 20 cm inter-row and 5 cm intra-row spacing as well as 121 kg NPS ha^{-1} even though different locations have different fertility status and need different management practices. Therefore, the present finding was initiated to determine economically optimum plant density and phosphorus level for Kik-type field pea production on Nitisols.

MATERIALS AND METHODS

Description of experimental area

The trial was conducted at Debre Markos Agricultural Research station during 2020 and 2021 cropping season. The trial site is located between Latitude 10°16'15 North and Longitude 37° 46' 47 East at an altitude of 2467 meters above sea level.The mean annual precipitation is 1482.30 mm. The rainfall distribution is unimodal and the rainy season is from May to September.

Soil sampling and analyses

Soil samples (0-30 cm) soil depth were taken and composited before the experiment and analyzed for soil pH (measured in water to soil water ratio of 1:2.5)(Landon, 1994), organic matter (organic carbon determined using wet digestion method)(Walkely and Black, 1934), total nitrogen (determined using the methods described by Kjeldahl method (Bremner and Mulvaney, 1982) and available phosphorous (determined using Bray II method (Bray and Kur, 1945).Cation exchangeable capacity (CEC) was measured using the methods ammonium acetate method (Chapman, 1965).

Treatments and experimental design

The treatments were a factorial combination of two levels of intra-row spacing (5, 10 cm), inter-row spacing (20, 30 cm), and five levels of phosphorous fertilizer (0, 23,46,69 and 92 kg ha^{-1})and laid out in Randomized Completely Block design (RCBD) with three replications. A field trial was conducted on Burkitu Kik-type field pea variety with a gross plot size of 1.8 m width x 5 m length (9.0) m2, and spacing between plots and blocks was 0.5m and 1.5 m respectively. The number of rows per plot for the 20 and 30cm inter-row spacing was 9 and 6 respectively; all the necessary data were collected from the central rows of 7 and 4 rows in 20 and 30 cm inter-row spacing, leaving one border row in each side. Phosphorous fertilizer in the form of TSP was used as a source ofP_2O_5.Beside to this, 18 kg N ha^{-1} fertilizer was applied uniformly for all experimental units at the time of planting. Weeding and other cultural practices were carried out as per the recommendation.

Data collection

Data on plant height, number of pods per plant, number of seeds per pod were taken from 10 randomly selected plants from each net plot area, while above ground biomass and grain yield were recorded from the net plot area after sun drying. Thousand seed weight was counted and weighed1000 seeds randomly taken from the bulked grain yield.

Statistical Data Analysis

The collected data were subjected to analysis of variance (ANOVA) using SAS software. Mean separation was computed using Duncan's Multiple Range Test (DMRT) at 5% level of significant. Combined data over years were analyzed since the variance was homogeneous tested using Levene's Test.

Economical data analysis

The economic analysis was performed according to the CIMMYT (1988) procedures. The total cost which varied between treatments (phosphorous fertilizer) was calculated during the time of planting. The mean yield over years was adjusted 10% downward to bridge the yield gaps between the experimental plots and farmers' fields. Gross benefit (GB) was calculated by multiplying the adjusted grain yield with the field price of field pea grain. Net benefit (NB) was calculated by subtracting the total variable cost from the gross benefit. Variable costs were ranked in ascending order and dominance analysis was conducted.Marginal rate of return (MRR) was computed by excluding the dominated treatments.

RESULTS AND DISCUSSION

Soil properties of the experimental site

Soil analysis revealed that the experimental site had a pH of 5.13, which is classified as strongly acidic (Landon, 1991). The pH range for optimal growth of field pea is 5.5 to 6.7 (Ahmed *et al.*, 2007). Organic carbon was 1.64%, which is considered low (Walkely and Black, 1934), and total nitrogen was 0.178%, which is medium (Landon, 1991), and available phosphorous was 7.99 ppm, which is low (Olsen, 1954) (Table 1). Cation exchange capacity was found to be medium (Landon, 1991). Overall, the soil analysis showed that the soil is depleted and needs organic inputs and crop rotation.

Table 1: Soil properties of the experimental site before planting

Soil characters	Values	Rating	References
pH (H_2O)	5.13	strongly acidic	Landon, (1991)
Organic C (%)	1.87	Low	Walkely and Black (1934)
Total N (%)	0.178	Medium	Landon (1991)
Ava. P (ppm)	8.793	Low	Olsen(1954)
CEC Cmol (+) / kg	20.76	Medium	Landon (1991)

Effects of P rate, Intra-row and Inter-row spacing on growth, yield and yield related traits of field pea

Plant height (cm)

Plant height was significantly ($P<0.001$) influenced only by the main effects of phosphorous fertilizer. Significantly, the maximum plant height (160.13 cm) was recorded from the application of 92 P_2O_5 kg ha^{-1} while the minimum (114.86 cm) was measured from the nil application of phosphorous fertilizer (Table 2). This might be because phosphorous fertilizer is essential for plant growth and development. Consistent with the current study, Mebrate and Abdisa (2023) also found that plant height increased as the amount of phosphorous fertilizer varied from 0 to 92 kg ha^{-1}.Beside to these Dawson (2019) observed that plant height of field was increased with increasing P level from 55 to 65 kg ha^{-1}.

Number of pods plant^{-1}

The main effects of intra-row spacing and phosphorous fertilizer had significant ($P<0.001$) effect on mean number of pods per plant. Moreover, number of pods per plant was significantly ($P<0.05$) influenced by inter-row spacing. Therefore, the maximum number of pods per plant (11.05) and the minimum (9.65) was observed for 10 and 5 cm intra-row spacing respectively. Likewise, Mebrate and Abdisa (2023) found that maximum number of pods per plant was observed at 10 cm intra-row spacing compared to 5 cm.Closely confirmed with the present study, Teklu and Solomon (2019) reported that maximum number of pods of faba bean was obtained from wider row spacing's.Contrary to the current study, Yayeh e*t al*. (2015) found that intra-row spacing had no significant effect on number of pods per plant.

In case of inter-row spacing, planting field pea using wider row spacing resulted relatively maximum number of pods^{-1} plant. This could be due to the advantage of wider row spacing for less competition of essential resources. In accordance with the present study Almaz *et al*. (2016) observed that wider inter-row spacing resulted maximum number of pods per plant on faba bean. Similarly, BA Bakery *et al*. (2011) also reported that number of pods per plant increased when faba bean was planted using wider inter-row spacing's.In contrast with the current result, Mebrate and Abdisa (2023) found no significant difference in the number of pods per plant based on inter-row spacing.

For phosphorous fertilizer, the maximum pods plant^{-1} (12.00) was achieved with field pea when planted at application of 92 kg P_2O_5 ha^{-1}, but was not statistically different from 46 and 69 kg P_2O_5 ha^{-1}, and the minimum pods plant^{-1} (8.04) was recorded from unfertilized treatment. Field pea pods per plant are known to increase with increasing phosphorous fertilizer (Mandloi*et al*. 2020). Number of pods per plant was also increased with increasing phosphorous fertilizer (Dawson 2022).

Number of seeds pod^{-1}

Analysis of variance revealed that number of seeds pod^{-1} was significantly ($P<0.001$) influenced by phosphorous fertilizer. However, number of seeds pod^{-1} was not significantly affected by the main factors of intra-row and inter-row spacing's as well as its interaction effects (Table 2).The highest mean number of seeds pod^{-1} (4.83) was found when field pea was grown with the application of 92 kgP_2O_5ha^{-1} while the lowest number of seeds (3.95) was obtained from non-phosphorous fertilizer applications.The results of the field pea experiment in this study are consistent with the results of a similar experiment done by Dawson (2022), who also found that the maximum number of seeds per pod was produced as the rate of phosphorous fertilizer was increased. Teklu and Solomon (2019), who also found maximum number of seeds per pod from the highest level of phosphorous fertilizer application, but in contrast, number of seeds pod^{-1} was not significantly affected by different levels of phosphorous fertilizer (Mebrate and Abdisa, 2023).

Table 2: Effects of intra-row spacing, inter-row spacing and phosphorous fertilizer on plant height, pod number plant^{-1} and seed number pod^{-1}

Treatments	Plant height(cm)	Pod number plant^{-1}	Seed number pod^{-1}
Intra row spacing (cm)			
5	144.43	9.65b	4.46
10	138.59	11.05a	4.60
Significance	Ns	**	Ns
Inter row spacing (cm)			
20	143.16	10.02b	4.45
30	139.52	10.68a	4.61
Significance	Ns	*	Ns
P_2O_5 (kg ha^{-1})			
0.00	114.86c	8.04c	3.95c
23	136.33b	9.79b	4.32bc
46	143.24ab	10.92a	4.73ab
69	152.23ab	11.00a	4.81a
92	160.13a	12.00a	4.83a
Significance	***	***	***
CV(%)	21.43	17.76	16.92

Means with the same column followed by the same letter (s) are not significantly different at 5% significant level; CV: coefficient of variance

Thousands seed weight (gm)

Different levels of phosphorous fertilizer had significant ($P<0.05$) effect on thousands seed weight of field, but intra-row and inter-row spacing main effects and interaction effects had no significant effect on thousands seed weight (Table 3). The maximum thousand seed weight (225.00 gm) was obtained from field pea planted at application of 92 kg P2O5 ha-1, which was statistically on par with 46 and 69 kg P2O5 ha^{-1} application.However, the minimum seed weight (205.00 gm) was recorded from the unfertilized treatments, while this variation in thousands seed weight may be attributed to the phosphorous fertilizer contribution for the development of normal seeds, as other researchers have also reported (Daniel and Tefese, 2018; Mandloi *et al*., 2020; Mebrate and Abdisa, 2023).

Biological Yield (kg ha^{-1})

The main effects of intra-row and inter-row spacing significantly ($P<0.01$) affected biological yield of field pea, as did the phosphorous fertilizer, which was also significantly ($P<0.001$) affected this trait (Table 3).The highest (5212.90 kg ha^{-1}) and the lowest (4652.70 kg ha^{-1}) biological yield of field pea was observed from the wider and narrow intra-row spacing, respectively. This differs from the finding of Yayeh et al. (2015), where maximum biological yield of field pea was achieved with narrower intra-row spacing than with wider rows. Regarding inter-row spacing the maximum biological yield (5225.30 kg ha^{-1}) was obtained from wider inter-row spacing than narrow spacing. The maximum biological yield observed from wider row spacing might be due to less competition of essential resources. Unlike with the current result, maximum total dry biomass yield of faba bean was observed from narrow inter-row spacing's compared to the wider rows (Almaz *et al*., 2016).

In case of phosphorous fertilizer better biological yield (5836.90 kg ha^{-1}) was recorded at 92 P_2O_5 kg ha^{-1} while the minimum yield (3775.10 kg ha^{-1}) was obtained from unfertilized treatment. Field pea fertilized with 92 P2O5 kg ha^{-1} had 35.32% biological yield advantage over the unfertilized treatment. This is in line with the current finding that biological yield of field pea was maximized at 92 P2O5kg ha^{-1} fertilizer application (Mebrate and Abdisa, 2023). Also, Daniel and Tefese (2018) reported that maximum yield increment of field pea was achieved at 69 kg ha^{-1} phosphorous fertilizer application.

Seed Yield (kg ha^{-1})

Analysis of variance revealed that seed yield was significantly ($P<0.01$) influenced by the main effects of intra-row and inter-row spacing. Moreover, phosphorous fertilizer was also significantly ($P<0.001$) affected seed yield of field pea. However, seed yield was not significantly affected by any interaction effects (Table 3).The highest mean yield of field pea was obtained at 30 and 10 cm between rows and plant spacing, respectively; whereas the lowest seed yield was obtained at 20 cm between rows and 5 cm between plants, which may be attributed to reduced competition for light, moisture, nutrients, and other resources; this was consistent with the finding of Mebrate and Abdisa, (2023) that maximum yield was achieved using wider row spacing.

In case of phosphorous fertilizer maximum seed yield of field pea (1942.39 kg ha^{-1}) was obtained from application of 92 kg ha^{-1} while the minimum (1190.70 kg ha^{-1}) seed yield was recorded from non-fertilized treatments.Yield advantage of 38.70%, 18.03%, 14.09% and 12.46% was recorded with application of 92 P2O5 kg ha^{-1} over 0, 23, 46 and 69 P2O5 kg ha-1 respectively. The observed variation in seed yield may be attributed to the critical role of phosphorous in field pea that result in enhanced and efficient nodulation, improved nitrogen assimilation, enhanced field pods and ultimately higher seed yield (Sundayand and Asabar, 2020). In line with the current study Daniel and Tefese (2018) confirmed that seed yield of field pea maximized with increasing phosphorous fertilizer application. Similar works done by Sunday and andAsabar (2018) indicated that increasing phosphorous fertilizer rate 0 to 60 kg ha^{-1} tends to increase the seed yield of field pea 1155.88 to 1857.00 kg ha^{-1}.

Table 3: Effects of intra-row spacing, inter-row spacing and phosphorous fertilizer on thousands seed weight, biomass and seed yield of field pea

Treatments	Thousands seed weight (gm)	Biomass yield kg ha^{-1}	Seed yield kg ha^{-1}
Intra row spacing (cm)			
5	215.75	4652.70b	1504.48b
10	219.20	5212.90a	1733.28a
Significance	Ns	**	**
Inter row spacing (cm)			
20	216.00	4640.30b	1530.11b
30	218.95	5225.30a	1707.65a
Significance	Ns	**	**
P_2O_5 (kg ha^{-1})			
0.00	205.00b	3775.10c	1190.70c
23	217.38ab	4910.10b	1592.18b
46	219.58a	4950.20b	1668.80b
69	220.00a	5191.90b	1700.34b
92	225.00a	5836.90a	1942.39a
Significance	*	***	***
CV(%)	9.77	20.93	18.57

Means with the same column followed by the same letter (s) are not significantly different at 5% significant level; CV: coefficient of variance

Economic Analysis

Partial budget analysis carried out for phosphorous fertilizer effects on field pea since there is no interaction between the factors.The net return ETB 66,369.26, with acceptable marginal rate of return, is obtained by applying 92 P2O5 kg ha^{-1}. Compared to the control treatment, this application gives an additional net benefit ETB 24,812.39. Hence, planting field with the application of 92P_2O_5kg ha^{-1} is economically feasible.

Table 4: Partial budget analysis as influenced by phosphorous fertilizer

Treatment (P_2O_5) kg ha^{-1}	Adjusted grain yield kg ha^{-1}	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
0.00	1071.63	41,557.81	0.00	41,557.81	-
23	1432.96	55,570.19	356.04	55214.15	3835.62
46	1501.92	58,244.46	712.00	57532.46	651.14
69	1530.31	59,345.42	1068.12	58277.30	209.20
92	1748.15	67,793.26	1424.00	66369.26	2272.77

Note: GB=gross benefit; TVC=total variable cost; NB=net benefit; MRR=marginal rate of return

CONCLUSIONS

Field pea is an important highland pulse crop.The seed yield and yield attributes of field pea are significantly improved by proper plant and row spacing and optimum phosphorous fertilizer.Application of 92 P_2O_5 kg ha^{-1}fertilizer increased seed yield with 38.70%, 18.03%, 14.09% and 12.46% over 0, 23, 46 and 69 P_2O_5 kg ha^{-1} respectively.Similarly, planting field pea using 10 cm intra-row and 30 cm inter-row spacing resulted better seed yield and yield components. Generally, planting field pea using 10 cm intra-row and 30 cm inter-row spacing with application of 92 P_2O_5 kg ha^{-1}found to be economically profitable and can be recommended in Aneded district and similar agroecologies. However, further research using different phosphorous levels, intra-row and inter-row spacing's should be conducted at different locations and seasons to come with conclusive recommendation.

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Data availability statement

The data supporting the conclusions of this article will be made available by the authors/corresponding author.

Author contributions

Data collection, data analysis, manuscript preparation, conceptualization

Conflicts of interests

The authors declare that no conflict of interest.

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