



Optimizing Phosphorus and Row Spacing Management for the Production of Lentil (*Lens culinaris* Medikus) in Vertisols of Ethiopia

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Authors' contributions

This work was carried out in collaboration among all authors. Authors GF, BT and SE designed the study, performed the field experiment, generated data, performed the statistical analysis and wrote the whole manuscript. Author AM edited, read and approved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Poor agronomic management such as nutrient management and plant density are critical challenges of lentil production in Ethiopia. Therefore, this study was conducted to determine the effects of different row spacing and phosphorus (P) applications on the seed yield of lentil at Ude and Minjar, in 2017 up to 2019. The experiment was conducted in completely randomized block design with three replications. The treatments were comprised of a factorial arrangement of three levels of row spacing (20, 30 and 40 cm) and four levels of P fertilizer (0, 30, 60 and 90 kg P₂O₅ ha⁻¹). The result revealed that at Ude, the row spacing x P fertilizer interactions was a significant effect on the biomass, seed, and haulm yield of lentil. However, at Minjar; only the main effects of row spacing and P fertilizer had a significant effect on biomass, seed, and haulm yield. Phosphorus agronomic use efficiency was significantly influenced by the interaction of row spacing and P fertilizer. As a result, the highest phosphorus agronomic use efficiency was recorded at 30 kg P₂O₅ ha⁻¹ coupled with 20 cm row spacing at both locations. The economic analysis revealed that 20 cm row spacing and 30 kg P₂O₅ ha⁻¹ fertilizer managements gave the highest net benefit and

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acceptable marginal rate of return (MRR) as compared to other practices at both locations. Therefore, 20 cm row spacing and 30 kg P₂O₅ ha⁻¹ rate of fertilizer would be recommended to enhance the productivity of lentil in the study areas.

Keywords: Lentil; nutrient; phosphorus; row spacing; yield.

1. INTRODUCTION

Lentil is an important cool-season food legume and 'break' crop in the highlands of Ethiopia [1]. The crop is very useful in a crop rotation system, where cereal mono-cropping has dominated [2]. Like other legume crops, lentil can fix atmospheric N and hence improves soil fertility, principally in poorer areas, besides human health by providing protein-rich grains [3]. In Ethiopia, the production area of lentil is cultivated on about 119,046.04 hectares and annual seed production is about 1.6 tones [4]. Despite the growing attention has given to lentil as a high-value commodity, the crop still considered as a subsistence crop, and the majority of farmers produce without fertilizer application. This is because of the historical generalization and assumption that legume can fulfill all of its nutrient requirements through the natural N-fixation and uptake of residual P from the soil. The Ethiopian highland *Vertisols* crop production is characterized by a subsistence rain-fed system where a large number of farmers depend on for livelihoods [5,6]. In this system, legumes are often considered as secondary to cereals and are generally promoted as crops that require no inputs. The beneficial effect of fertilizer application (specifically NPK, and occasionally S) on legume yield gains is a fact across the world [7,8].

Phosphorus (P) is critical in plant metabolism which plays an important role in cellular energy transfer, respiration, photosynthesis and it is a key structural component of nucleic acid coenzymes, phosphor-proteins, and phospholipids. Research results showed that P has a positive effect on nodule formation and nitrogen fixation in legume crops [9]. The lentil crop can be quite responsive to P fertilization, particularly where soils test low in available P [10]. However, little is known on the impact of P applications on lentil grain yield, and its nutrient requirement. Some outdated research findings in Ethiopia revealed non-significant difference between P-fertilized and their unfertilized counterparts [11]. However, these earlier studies had at least two technical limitations: soil P status before conducting the trials was not

studied and all the trials were conducted on a single testing site and critically lacking both sites as well as seasonal replication (i.e., the wide-ranging growing conditions were not adequately represented). Hence, it is evident that earlier studies on the responses of lentil to P fertilizer application, in general, were not adequately studied. Elsewhere, several investigators have reported the positive response of lentil to the application of P fertilizer during planting, which also enhanced seedling development and plant growth [12]. Further, [10,13] determined the nutritional requirement of lentil and reported that lentil cultivars studied attained their highest yields using 20 kg P ha⁻¹ to 52.2 kg P ha⁻¹.

On the other hand, optimum plant density is one of the significant factors that affect yield and quality of lentil. The yield response of lentil to planting density has been discussed by several workers, and different relative responses for haulm and seed yield to planting density were found [14,15,16,17]. Parveen and Bhuiya [18] reported that the highest plant population per unit area gave the highest yield for lentil crops. However, plant density is determined by cultivar and soil fertility; because of the wide range of growth habits among cultivars and soil nutrient viabilities in the fields. In addition to this, an optimum level of single factor may not cause an appreciable increase in the yield itself, but a combination of factors contributes to the ultimate yield of lentil. Therefore, this investigation was aimed at determining appropriate row spacing and phosphorus fertilizer rates to enhance the productivity of lentil.

2. Materials and Methods

2.1 Description of the Study Sites

The trials were carried out on a farmer's field under the rain-fed condition for three consecutive cropping seasons (2017 to 2019) at Ude and for two consecutive cropping seasons (2017 and 2018) at Minjar. Ude is located in East Shewa Zone of Oromia Regional State of Ethiopia. It is found at 52 km away from South East of the capital city of Ethiopia, Addis Ababa. Its geographical location is 9°5'52.8" N and

36°58'37.2" E. The altitude is about 1970 meter above sea level while the majority of soil type is heavy black soils (*Vertisols*). Total rainfall during lentil growing months in the year 2017, 2018, and 2019 was approximately 609.8.6 mm, 460.9 mm, and 656.9 mm, respectively (Fig. 1a). The average minimum and maximum temperatures were 18.3, and 23.8 °C for 2017, 18.1 and 23.7 °C for 2018, and 17.9 and 23.3 °C for 2019, respectively. Minjar is located in North Shewa Zone of Amhara Regional State of Ethiopia. It is found at 147 km away from North East of the capital city of Ethiopia, Addis Ababa. Its geographical location is 9.09 latitude and 39.19 longitudes. The altitude is about 1040 meter above sea level. The soil type is slightly *Vertisols*. Total rainfall during lentil growing months in the year 2017, 2018 and 2019 was approximately 698.2mm, 521.6 mm and 805.3mm, respectively (Fig. 1b). The average minimum and maximum temperatures were 14.7 and 25.8 for 2017, 14.4 and 25.6 for 2018 and 14.8 and 24.8 for 2019, respectively.

2.2 Soil Physico-chemical Properties before Planting

Some of the selected soil physico-chemical properties of the experimental site are shown in Table 1. On the basis of particle size distribution, the soil contains 29% sand, 41% silt and 31% clay at Ude site and 35% sand, 32% silt and 34% clay at Minjar site (Table 1). According to the soil

textural class determination triangle, the soils of the experimental sites were dominantly silt at Ude and sand at Minjar. The texture indicated the degree of weathering, nutrient high and water holding capacity of the soil. High silt content may indicate the better water and nutrient holding capacity of the soil at Ude but the reverse is true at Minjar sites. According to the nutrient class range identified by [19], soils containing Olsen P less than 10 ppm are considered as low in available P, those grouped in the range of 10-20 ppm are considered as medium and the rest containing greater than 20 ppm are classified as high in available P. Thus, the experimental soil is low in available P (5.7 ppm) at Ude and 7.3 ppm at Minjar, which indicated the requirement of P fertilizer application at both locations for optimum crop growth and yield [20]. The soil reaction of the experimental sites was silently alkaline at Minjar while it is neutral at Ude, where the pH was 8 and 7 respectively. This indicates that the soil reaction of the experimental sites is suitable for optimum growth and yield of this crops especially for Ude. The CEC value of the soil was high at Ude and low at Minjar this indicates that the soil has relatively capacity to hold nutrient cations and supply to the crop. Tekalign [21] soils having total N of greater than 0.25 % are classified as very high, 0.12 - 0.25 % high, 0.01 - 0.12 % medium and less than 0.01% low in total nitrogen content. Thus, the soil of the experimental site has very high at Ude and Minjar in total nitrogen content.

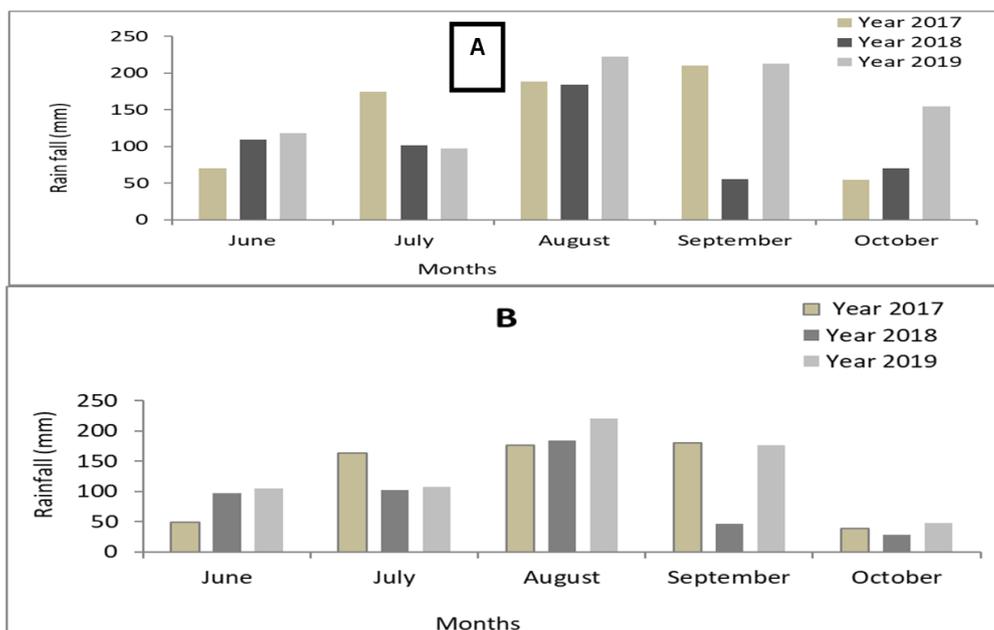


Fig. 1. Rainfall distribution of lentil growing months during 2017 to 2019 at Ude (A) and Minjar(B)

Table 1. Soil physio-chemical properties analysis at Ude and Minjar

Soil Property	Ude			Minjar		
	Depth (cm)			Depth (cm)		
	0-15	15-30	30-60	0-15	15-30	30-60
Clay (%)	31.6	29.1	31.9	33.1	33.7	34.5
Silt (%)	40.5	42.3	39.1	32.6	31.7	30.7
Sand (%)	27.9	28.6	29.0	34.3	34.6	34.8
pH (1: 2.5 H ₂ O)	7.3	7.4	7.4	7.5	7.5	7.8
CEC [Cmol(+) kg ⁻¹ soil]	38.7	39.0	39.3	37.2	37.0	37.8
Organic matter (%)	1.87	1.24	0.89	1.55	1.27	0.91
Total N (%)	1.73	1.40	1.16	0.73	0.40	0.16
Available P (mg/kg)	7.21	5.32	4.58	10.11	6.18	5.54

2.3 Experimental Treatments, Design and Field Managements

The trial was laid down a completely randomized block design (RCBD) in a factorial arrangement replicated three times. The treatment consisted of four phosphorus levels (0, 30, 60 and 90 kg P₂O₅ ha⁻¹) which is applied at 2 cm depth and three different rows spacing (20, 30 and 40 cm). The plot size of 3m x 3m (9 m²) was used for the experiment. The experimental field was tilled with oxen plough by local 'Marsha', which is slow-moving at about 0.2m depth and involves pushing soil to left and right with partial inversion. The first and second tillage were in late May and early June at Ude and in mid-June and late-June at Minjar, respectively, while the third tillage was at planting time. The crop was planted on 22, 24 and 23 July in 2017, 2018 and 2019, respectively at Ude. While at Minjar, it was planted on 18 and 20 July 2017 and 2018, respectively. Lentil variety *Alemaya* was used and a seed rate of 80 kg ha⁻¹ were sown by hand drilling. Weeding was done manually at two times. Harvesting was done from net plot area by eliminated one row from each side and 0.2 m from the heads of the plots.

2.4 Data Collection and Measurements

Observations on days to 50% flowering and days to 90% maturity were recorded on the plot basis of each site. Plant height, number of pods plant⁻¹, and number of seeds pod⁻¹ were taken from randomly selected 10 plants from middle rows. At maturity, the whole aboveground plant parts, including leaves, stems, and seeds from the net plot area in each plot was harvested and sun-dried for 6 days until constant weight and then the aboveground biomass was weighed and expressed in kg ha⁻¹. Seed yield from the net plot area of each plot was recorded by measuring the

seed yield and adjusted at 10% seed moisture content. Haulm yield per net plot was calculated by subtracting total seed yield weight from the total biomass yield for the respective treatments. Later the haulm yield ha⁻¹ were computed and expressed in kg ha⁻¹. To compare the economic advantages of applied P fertilizer rates with the control were carried out using partial budget analysis. In this experiment, the costs that vary were calculated by adding the costs of fertilizer and labor for fertilizer application. However, other management and fixed costs were assumed to be constant for all and not included in the calculation. The cost of P fertilizer was 1450 Birr/100 kg. The price of the lentil seed was 55.50 ETB kg⁻¹. The average seed yield was adjusted down ward by 15%, where 10% to reflect the difference between the experimental yield and the farmers' yield that expected from the same treatment and 5% was considered for the plot size. Following the CIMMYT partial budget analysis methodology, total variable costs (TVC), gross benefits (GB), and net benefits (NB) were calculated. To identify treatments with maximum return to the farmer's investment, marginal analysis was performed on non-dominated treatments. For a treatment to be considered as a worthwhile option to farmers, the marginal rate of return needs to be at least 100% [22].

2.5 Phosphorus Agronomic efficiency (PAE)

PAE is defined as the quantity of grain yield per unit of nutrient applied

$$PAE (kgkg^{-1}) = \frac{Gf - Gu}{Na}$$

Where Gf is the grain yield of the P fertilizer plot (kg), Gu is the grain yield of the unfertilized plot (kg) and Na is the quantity of P applied (kg).

2.6 Statistical Analysis

Data were tested for normality using normal probability plot followed the data were subjected to the combined analysis of variance (ANOVA) over years after confirmation of homogeneity of error variance using the SAS-software program. Separate analyses were conducted for each location because of the heterogeneity of error variance. The means were compared by the least significant difference (LSD) method at 0.05 probability level.

3. RESULTS AND DISCUSSION

3.1 Lentil Phenology

The combined analysis result showed a wide range of fluctuation in lentil phenology and plant height depending upon P fertilizer rate, row spacing and years as illustrated in Table 2. The main effect of P fertilizer on the days to flowering, days to maturity, and plant height of lentil were significant at Minjar, but at Ude these parameters were not significant. Prolonged days to flowering (65 days) and physiological maturity (111 days) were observed at the control plot, while earlier flowered (57 days) and matured (103 days) of lentil was recorded at 60 and 90 kg P₂O₅ ha⁻¹, respectively. In contrast, the maximum (47cm) and minimum(40cm) plant height of lentil was measured at 60 kg P₂O₅ ha⁻¹ and nil application of phosphorus fertilizer respectively. The hastening of days to flowering with P fertilizer might be due to the fact that applied P fertilizer increased the rate of crop development from emergence to floral initiation and advanced anthesis. Application of P could prevent the delaying in flower formation and also prevent the reducing the number of flowers per plant [23]. However, higher dose of P induces early flowering due to increment in nitrogenase activity of root nodules [24]. Increasing level of P from nil to 90 kg P₂O₅ ha⁻¹ significantly shorten the time of field maturity since it promotes rapid cell division. Similarly, [13] reported that applied P from nil to 30 kg P ha⁻¹ significantly shorten the physiological maturity of lentil. Variation on the days to flowering and maturity were by the P fertilizer rate were also reported by [10,1]. Amendment with P fertilizer resulted in the higher plant height improvement, averaging 13% improvement relative to the control (nil application of P). The higher plant height by P application was obtained from 60 kg P₂O₅ ha⁻¹ rather than 90 kg P₂O₅ ha⁻¹, which might be due to stimulation of biological

activities in the presence of balanced supply of phosphorus. Several studies reported that plant height increases with increment in phosphorus dose, the maximum plant height was obtained at 60 kg ha⁻¹ compared to 30 kg ha⁻¹ [25]. Generally, in pulses the balanced supply of nutrients increases the biological activities which stimulate the plant height [26].

At Ude the effect of row spacing was significant only on days to flowering, but at Minjar days to flowering, days to maturity, and plant height were not significant. The longest days to flowering (55 days) was recorded at 20 cm row spacing whereas the shortest (54 days) was recorded from the wider (40 cm) row spacing management (Table 2). The prolonged days to flowering in the narrow plant spacing was attributed to faster canopy closure and reduced soil moisture loss through evaporation between the rows, which ultimately took longer days of flowering. A prolonged day to flowering produced by narrow row spacing of lentil has been reported previously [10]. At both locations, lentil plant height was varied more with year compared with row spacing and phosphorus fertilizer. At Ude, plant height in 2019 was higher than in 2017. However, at Minjar plant height of lentil in 2017 was higher than in 2018. The year differences in plant height might be due to the irregularly distributed rainfall amount and its distribution in the cropping seasons (Fig.1).

3.2 Lentil Yield Components

The main effect of P fertilizer rate significantly affected the number pods per plant and seeds per pod of lentil at both Ude and Minjar location. There were also statistical differences (P<0.05) among the number of pods plant⁻¹ over year at Ude (Table 3). However, main effect of row spacing and interaction effect at both locations had not a significant effect on the number pods plant⁻¹ and seeds pod⁻¹ of lentil. At both Ude and Minjar location, the highest (51.5 and 51.4) number of pods per plant and seed (1.5 and 1.6) per pod were recorded at 60 kg P₂O₅ ha⁻¹, but statistically at par with 30 and 90 kg P₂O₅ ha⁻¹. While the lowest number of pods (35.6 and 37.6) pods per plant and seeds (1.2 seed per pod) were obtained from the control treatment respectively (Table 3). The current result indicated that the number of pods per plant and seeds per pod were enhanced by the application of P fertilizer up to 60 kg P₂O₅ ha⁻¹, but beyond that, the number of pods and seeds tended to decrease. This may be due to manipulation of

photosynthesis and remobilization of assimilates for pod formation. Furthermore, P fertilization might stimulate the plant for flowering and fruiting which leads to produce more pods [26]. The improvement of seed per pod with P application might be due to more supply of P increase the vegetative growth but not reproductive. Similar results were reported by [27,28]. The overall means regardless of row spacing and P fertilizer

effect, the highest number of pods (55.8 pods per plant) was obtained in 2019 cropping season, while the lowest number of pods (37.2 pods per plant) was obtained in 2018 cropping season at Ude (Table 3). This might be the distribution and amount of rainfall registered during the cropping periods (Figs. 1a and b) encouraged variations in number of pods plant⁻¹ of lentil.

Table 2. Means of lentil phenology at different row spacing and phosphorus applications at Minjar and Ude from 2017 to 2019 cropping years

Treatment	Minjar			Ude		
	Days to flowering	Days to maturity	Plant height(cm)	Days to flowering	Days to maturity	Plant height(cm)
Year						
2017	60.2	107.8	46.81a	56.2	103.8	42.2b
2018	61.0	106.2	42.24b	55.5	105.6	41.0b
2019	-	-	-	54.5	103.5	53.2a
Row spacing						
20 cm	61.3	107.7	46.50	54.9a	103.3	46.4
30 cm	59.8	103.9	44.10	54.8a	103.9	47.0
40 cm	60.7	106.4	42.97	53.9b	103.4	47.9
Phosphorus (kg P ₂ O ₅ /ha)						
0	65.3a	111.3a	40.48b	54.3	103.3	46.6
30	59.9b	104.6b	45.79a	54.7	104.2	47.2
60	57.2b	104.3b	46.52a	54.2	104.0	47.2
90	60.0b	103.7b	45.30a	54.9	102.7	47.5
CV (%)	8.6	6.4	14.3	2.6	2.1	7.1
Row spacing X P	ns	ns	ns	ns	ns	ns

Means with the same letter in columns are not significantly different at 5% level of significance; LSD= least significant differences at 5%; CV (%) = Coefficient of variation

Table 3. Means of some yield components at different row spacing and phosphorus applications on lentil at Minjar and Ude from 2017 to 2019 cropping years

Treatment	Minjar		Ude	
	Number of pods plant ⁻¹	Number of seeds pod ⁻¹	Number of pods plant ⁻¹	Number of seeds pod ⁻¹
Year				
2017	46.1	1.6	41.5b	1.4
2018	42.3	1.5	37.2b	1.3
2019	-	-	55.8a	1.4
Row spacing				
20 cm	46.4	1.5	46.8	1.2
30 cm	43.3	1.4	43.2	1.3
40 cm	42.7	1.6	49.6	1.4
Phosphorus (kg P ₂ O ₅ /ha)				
0	37.6b	1.2b	35.6b	1.2b
30	44.5ab	1.6a	50.9a	1.4a
60	51.4a	1.6a	51.5a	1.5a
90	43.1b	1.6a	48.0a	1.4a
CV (%)	25.9	18.9	18.2	22.9
Row spacing x P	ns	ns	ns	ns

Means with the same letter in columns are not significantly different at 5% level of significance; LSD= least significant differences at 5%; CV (%) = Coefficient of variation

3.3 Lentil Seed Yield, Biomass and Haulm Yield

The effects of different phosphorus and row spacing on lentil seed, biomass, and haulm yields at Minjar was illustrated in Table 4, and at Ude in Fig. 2A, B and C. At both location the effect of years had a significant effect ($P < 0.05$) on the abovementioned parameters. The main effects of row spacing and P fertilizer had significantly affected the biomass, seed, and haulm yield of lentil at Minjar. However, the interaction effect of row spacing with P had not significant at Minjar. At Ude, significant effects were observed by the interaction of row spacing with P fertilizer rate.

The highest biomass, seed, and haulm yield were significantly higher in 2017 cropping year than in 2018 cropping year. The increase in biomass, seed, and haulm yields in 2017 over 2018 cropping year were 16.1, 11.5, and 20.9%, respectively (Table 4). The differences in the crop yield under different cropping years might have resulted from an early offset of the rainfall in the 2018 year (Fig. 1b) as such the crop was not fully matured. At Minjar, the highest biomass, seed, and haulm yields were achieved in the 20 cm row spacing, while the lowest was observed in the 40 cm row spacing. The narrower row spacing (20 cm) increased biomass, seed, and haulm yields by 16.5, 13.4 and 17.2%, respectively over the wider row spacing (40 cm). The lowest productivity of lentil in wider (40 cm) row spacing compared to the narrow (20 cm) row spacing resulted from reduced plant population per unit area. On the other hand, increasing in biomass, seed, and haulm yield with the narrow row spacing was attributed to increasing plant population per unit area. The yield increase observed with the increase in plant density was a function of more pods being produced as a result of more plants being established [10]. In agreement with this finding, Akter [29] reported that narrow row spacing (20 cm) produced a higher yield than wider row spacing (30 cm) with a normal seed rate of lentil. Similarly, [30,31] reported higher biomass and seed yield of faba bean in narrower spacing under *Vertisols* and *fluvisol*. Similarly, the highest biomass and haulm yield from the highest rate (90 kg P_2O_5 ha⁻¹) than in the yield from the control plots (Table 4). Mean biomass and haulm yield were increased by 22.9 and 17.5%, respectively, over the untreated plots (nil P application). These increments of biomass and haulm yield of lentil at the highest rate of P application might be due to availability of P nutrient in the soil which increases their uptake

by plants, which result in increased dry matter accumulation in leaves and stem at earlier growth stages and better translocation to yield during later stages. As [32,13] reported an increased rate of phosphorus application from 0-30 kg ha⁻¹ increased dry matter of lentil. In contrast, the seed yield was significantly lower at highest rate (90 kg P_2O_5 ha⁻¹) than at 30 and 60 kg P_2O_5 ha⁻¹ (Table 4). The highest seed yield was obtained at the application of 60 kg P_2O_5 ha⁻¹ but statistically at par with 30 kg P_2O_5 ha⁻¹. The increase in yield of 60 kg P_2O_5 ha⁻¹ and 30 kg P_2O_5 fertilizer rate, were accounted by 18.8%, and 13.1%, compared to the untreated plot. This might be due to the low availability of P (10.34 mg kg⁻¹) in the soil for the study site (Table 1), thus application of optimum P might have positive effects on the yield component parameters likes number of pods plant⁻¹, seeds pod⁻¹ and branches number cumulatively increased seed yield. Lentil grown on low P soil can respond to phosphate fertilizer [1]. These results conform to the findings of [33,28,13] who reported enhanced seed yield of lentil by application of P fertilizers.

At Ude, the highest seed yield (34.9%) and biomass (36.3%) was obtained from the interaction 20 cm row spacing and 30 kg P_2O_5 ha⁻¹ fertilizer application (Fig. 2a and c), respectively. In contrast, the lowest seed and biomass yield were obtained from the interaction of 40 cm row spacing and control plots (Fig. 2a and c), respectively. This yield advantage might be due to the positive effect of P fertilizer and optimum plant population per unit area that had increased pods number and number of seeds that cumulatively increased the yields. Further, narrow row spacing resulted in faster canopy closure and reduced soil moisture loss through evaporation between the rows, and also encouraging quicker rooting exploitation of the soil between the rows. Phosphorus promotes the development of extensive root systems and vigorous seedlings. Encouraging vigorous root growth is an important factor in promoting good nodule development [34]. Phosphorus also plays an important role in the nitrogen-fixing process and in promoting earlier, more uniform maturity [9]. This result is in agreement with [25,35] who reported that the application of phosphate fertilizer is a linear relationship with mean legumes (faba-bean and field bean) seed yield with an advantage of 55, 103, and 152% over the control. [13] also reported significantly higher seed yield of lentil with the application of 20 kg P_2O_5 ha⁻¹ at 30 cm row spacing.

Table 4. Means of biomass, seed and haulm yield of lentil effects by different row spacing and phosphorus application at Minjar in 2017 to 2018cropping season

Treatment	Biomass yield (Kg ha ⁻¹)	Seed yield (Kg ha ⁻¹)	Haulm Yield (Kg ha ⁻¹)
Year			
2017	7466.1a	1206.9a	6397.6a
2018	6265.6b	1068.5b	5058.7b
Row spacing (cm)			
20	7343.8a	1262.7a	6081.1a
30	7123.7a	1057.8b	6065.9a
40	6130.2b	1092.7b	5037.5b
Phosphorus (kg P ₂ O ₅ ha ⁻¹)			
0	5859.4b	1063.6b	4795.8c
30	6772.6a	1223.8ab	5648.8b
60	7236.1a	1309.1a	5927.0ab
90	7595.5a	1054.4b	6541.0a
CV (%)	17.9	18.9	22.0
Row x P	ns	ns	ns

Means with the same letter in columns are not significantly different at 5% level of significance; LSD= least significant differences at 5%; CV (%) = Coefficient of variation

Similar to the biomass and seed yield, the effects of row spacing and P fertilizer rate on the haulm yields of lentil were varied (Fig. 2b). In 20 cm row spacing interaction with 90 kg P₂O₅ ha⁻¹ fertilizer gave the highest mean haulm yield of lentil, which increased by 50.7% over the interaction of wider row spacing (40 cm) with control (nil kg P₂O₅ ha⁻¹) (Fig. 2b). In general, haulm yield obtained from the narrow row spacing (20 cm) with the highest rate (90 kg P₂O₅ ha⁻¹) of fertilized plot exceeded the haulm yield by two-fold over the wider row spacing (40 cm) with an untreated plot. The significant increase in haulm yield in response to the interactions of row spacing and P fertilizer management as compared to the other row spacing and P rate interaction may be attributed to the role of P nutrient and better stand establishments per unit area, which played in enhancing the biomass production. Similarly, [28,13] reported that dry biomass yields increased as the rate of P application increased from the control to the 20 kg ha⁻¹ of P application on lentil. Haulm yield is directly correlated to growth parameters like plant population per unit area plant height and biomass yield.

3.4 Phosphorus Agronomic use Efficiency

Phosphorus agronomic use efficiency was influenced by phosphorus applications rate and row spacing management at both locations (Fig. 3). The highest phosphorus agronomic efficiency (PAE) of 18.7 and 8.5 kg kg⁻¹ were obtained at 30

kg P₂O₅ ha⁻¹ application coupled with 20 cm row spacing at Ude and Minjar, respectively (Fig. 3). However, the least PAE value was noted at 90 kg P₂O₅ ha⁻¹ application with 40 cm row spacing in all treatments across both sites. This result showed that application of P fertilizer above 30 kg P₂O₅ ha⁻¹ coupled with 20cm row spacing had no appreciable effect on lentil grain yield. Regardless of row spacing, the higher the rates of P application, the lower were the agronomic efficiency in all observed treatments at both sites. This might be due to fixation of P in the soil and attributed to operation of law of diminishing marginal production. Similar to this result, [36,13] reported that phosphorus agronomic use efficiency of lentil was significantly declined with increasing levels of P without considering lentil varieties.

3.5 Partial Budget Analysis

Lentil production under row spacing and P fertilizer management involved different costs, which affected the total production cost that varied within each treatment (Table 5 and 6). It is quite evident from the data presented in Table 5, that the highest mean net benefit (92130 ETB ha⁻¹) with acceptable MRR (4221.7%) was obtained in the application of 30 kg P₂O₅ ha⁻¹ with 20 cm row spacing at Ude. In contrast, the lowest mean net benefit (63245 ETB ha⁻¹) was obtained from the control (unfertilized) plot (Table 5). However, at Minjar the highest mean net benefit (57766.1ETB ha⁻¹) with acceptable MRR (796.01%) was obtained in the application of 60

kg P₂O₅ ha⁻¹, but the mean net benefit difference forms the rate of 30 and 60 P₂O₅ ha⁻¹ are not more (Table 6). Therefore, on economic grounds,

the application of 30 kg P₂O₅ ha⁻¹ with 20 cm row spacing would be the economical best reward for the production of lentil in the study areas.

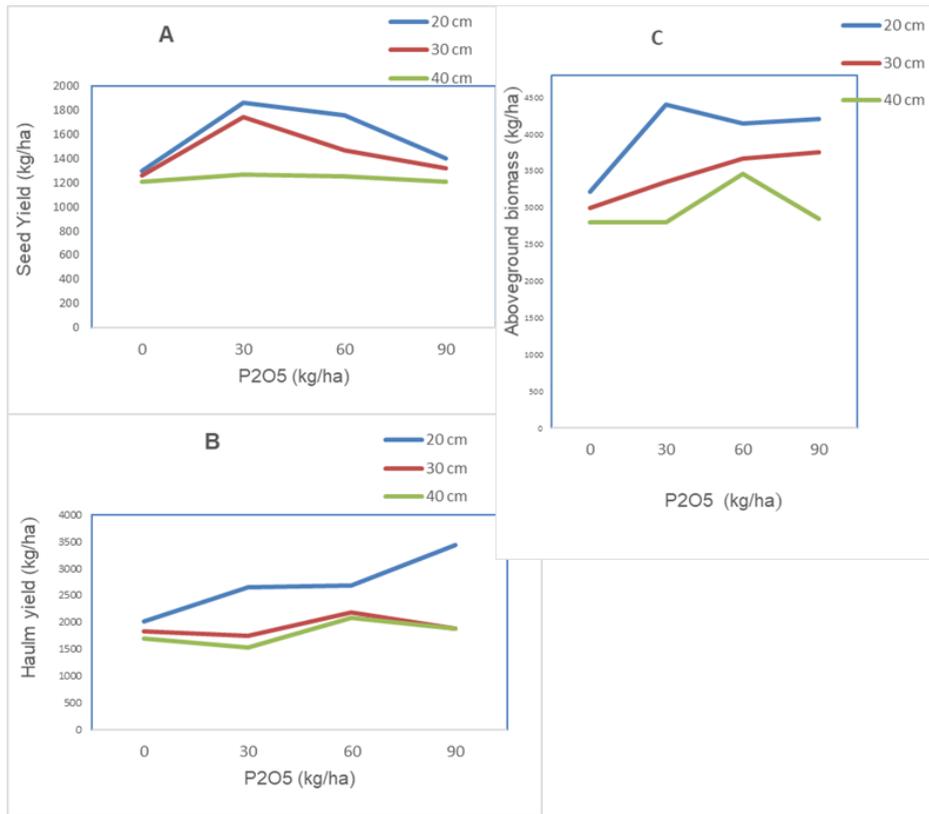


Fig. 2. Phosphorus fertilizer rate and row spacing interaction effect on lentil seed yield(A), haulm yield (B) and aboveground biomass yield(C) (kg ha¹) at Ude in 2017-2019 combined

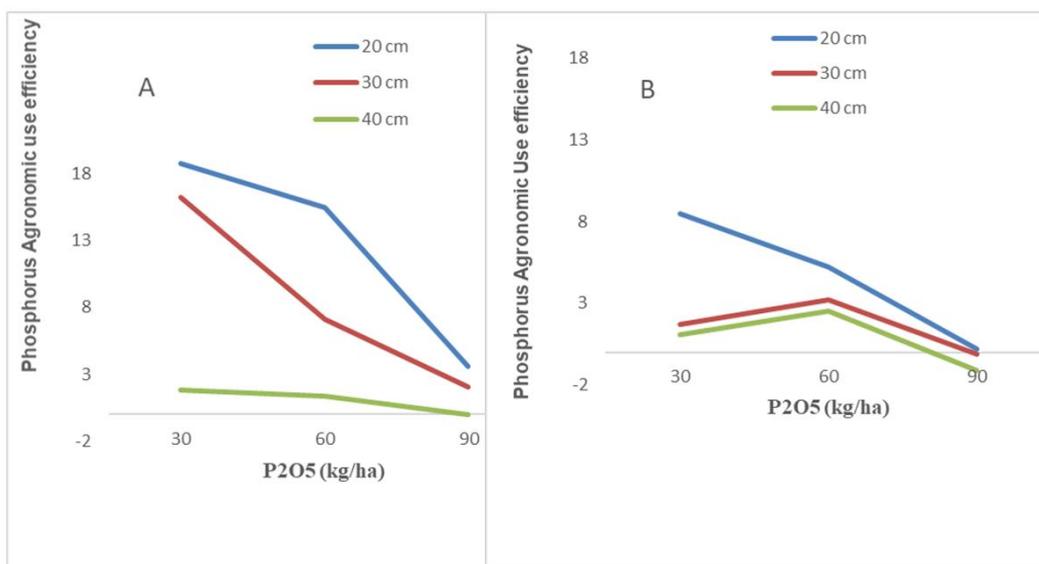


Fig. 3. Phosphorus fertilizer rate and row spacing interaction effect on lentil phosphorus agronomic use efficiency (kg kg⁻¹) at Ude (A) and Minjar (B) in 2017-2019 cropping season

Table 5. Partial budget analysis at Ude

Row Space	P ₂ O ₅ (Kg ha ⁻¹)	ASY (kg ha ⁻¹)	TGB (ETB ha ⁻¹)	TVC (ETB ha ⁻¹)	NB (ETB ha ⁻¹)	MRR (%)
20	0	1264.9	63245	0	63245	DM
30	0	1387.2	69360	0	69360	DM
40	0	1238.9	61945	0	61945	DM
20	30	1856.9	92845	715	92130	4221.7
30	30	1744.1	87205	715	86490	DM
40	30	1263.3	63165	715	62450	DM
20	60	1757.8	87890	1143.4	86746.6	5671.5
30	60	1469.6	73480	1143.4	72336.6	DM
40	60	1450.2	72510	1143.4	71366.6	MD
20	90	1302.4	65120	2151.6	62968.4	DM
30	90	1717.7	85885	2151.6	83733.4	DM
40	90	1307.8	65390	2151.6	63238.4	DM

AGY=Adjusted see yield; TGB= total gross benefit; TVC=Total variable cost, NB=Net benefit, MRR=Marginal rate of return

Table 6. Partial budget analysis at Minjar

P ₂ O ₅ (kg ha ⁻¹)	GY (Kg ha ⁻¹)	ASY (Kg ha ⁻¹)	TGBY (ET Birr)	TVC (ET Birr)	NB (ET Birr)	MRR (%)
0	1063.6	957.24	47862	0	47862	DM
30	1223.8	1101.42	55071	715	54356	908.25
60	1309.1	1178.19	58909.5	1143.4	57766.1	796.01
90	1054.4	948.96	47448	2151.6	45296.4	DM

AGY=Adjusted grain yield; ASY= Adjusted straw yield; TGB= total gross benefit; TVC=Total variable cost, NB=Net benefit, MRR=Marginal rate of return

4. CONCLUSION

Based on the result, row spacing and P fertilizer managements had a significant effect on growth, yield components, and yield of lentil. The highest economical yield was obtained from the interaction of narrow (20 cm) row spacing and 30 kg P₂O₅ at Ude. At Minjar, there was an economical yield advantage due to the 60 kg P₂O₅ ha⁻¹ fertilizer rate. However, the economic analysis showed that 20 cm row spacing and 30 kg P₂O₅ ha⁻¹ fertilizer managements are the economical best bit for farmers for both locations. Thus, for this row spacing and rate of fertilizer would be recommended for the study area.

DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon request.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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