

Response of Improved Lentil (*Lens Culinaris Medik*) Varieties to Phosphorus Nutrition on Vertisols of West Showa, Central Highlands of Ethiopia

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Received date: October 04, 2017; Accepted date: October 24, 2017; Published date: October 27, 2017

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Abstract

Identification of appropriate varieties and rates of phosphorus fertilizer for different sites are important agronomic practices to increase the productivity of lentil. A field experiment was conducted during the 2016 main cropping season to evaluate the performance of lentil varieties and their response to phosphorus application on vertisols of Ambo. Four Lentil varieties (Gudo, Alemtena, Teshale and EL-142) with four rates of phosphorus (0, 10, 20 and 30 kg/ha) were combined factorially in randomized complete block design with three replications. Varieties were significantly varied in days to 50% flowering and 95% maturity, number of nodules, plant height and biological yields. Application of phosphorus rate was significantly affected days to emergency, days to 50% flowering, days to maturity, number of nodule per plant, nodule dry weight, nodule volume, number of primary and secondary branches, number of pods per plant, number of seeds per pod, thousand-seed weight, plant height, grain yield, biological yields and harvest index of lentil varieties. Significant interaction effects of varieties and Phosphorus rate was observed with respect to 50% flowering, biological yields, number of nodules per plant and plant height of lentil varieties. All varieties showed better performance on various growth and phenological characters in response to phosphorus application. Application of 20 kg P ha⁻¹ was gave better yield and yield components of lentil. The highest net benefit of 72240 EB ha⁻¹ with marginal rate of return of 1177% was obtained from application of 20 kg P ha⁻¹, which was followed by 62706 and 55188 EB ha⁻¹, and marginal rate of return 1445 and 243 % with application of 10 and 30 kg P ha⁻¹, respectively. Therefore, application of 20 kg P ha⁻¹ is recommended to sustain lentil production in vertisols of Ambo areas in central highlands of Ethiopia.

Keywords: Variety; Phosphorus rates; Agronomic efficiency; Seed yield

Introduction

Lentil (*Lens culinaris Medik*) is one of the most ancient annual food crops that have been grown as an important food source for over 8,000 years [1]. Lentil is an important pulse crop grown widely throughout the Indian Subcontinent, Middle East, Northern Africa, Southern Europe, North and South America, Australia and West Asia [2]. Ethiopia is amongst the centers of diversity for lentil [3].

Ethiopia is one of the major lentils producing country in the world and the first in Africa [4]. According to [5] in Ethiopia, 1,652,844.19 hectares of land are allocated for pulse crops production with total production 27,692,743.11 quintals; out of which 100,692.74 hectares is cultivated with lentil, which accounts for 1,339,336.41 quintals of yield. In West Showa Zone, lentil accounts from 54,636.28 hectare of land for total pulse cultivation, 1,842.99 hectare area cultivated for lentil producing 27,204.57 quintals [5] with average seed yield of 14.76 quintal ha⁻¹.

Lentil is grown for human consumption it's seed contains 1-2% fat, 24-32% proteins and minerals and vitamins [6] and therefore, may correct important amino acid deficiencies of cereals when used in mixture with cereal crops. Abraham [7] reported that the crop is important export and cash crop that has highest price in domestic market compared to all other food legumes and cereals. Moreover,

Lentil can fix atmospheric nitrogen through root nodules in association with Rhizobium bacteria. This improves the physical, chemical and biological properties of soil and may in addition reduce the pressure of nitrogenous fertilizer application to the crop [8].

Despite its importance, production of lentil in Ethiopia is characterized by a low mean yield of 1.39 t·ha⁻¹ [9]. This low seed yield has been attributed to inadequate agronomic management practices, use of local variety, planting on marginal lands without any fertilizer application and lack of indigenous rhizobial symbionts of lentil in the soil as a result of continuous cereal mono-cropping system [10]. The susceptibility of the landraces to diseases, the inherently low yield potential of landraces and poor agronomic practices [11].

Phosphorus (P) is major nutrient elements for grain legumes. Phosphorus has very positive effects on nodule formation and nitrogen fixation in legume crops [12]. Phosphorus is a constituent of nucleic acids, phospholipids and ATP [13]. Even though addition of P fertilizer increases grain yield in many crops such as common bean [14] and soybean [15], Faba bean [16], chickpea [17], cowpea [18]. The application of excess P fertilizer has been associated with environmental pollution [19].

Despite the presence of a large P pool, Africa is suffering from shortage of available P, which remains a yield limiting factor [20]. Available P is often a limiting element in crop production in central Ethiopian highlands [21] with 70 to 75% of the agricultural soils deficient in phosphorus [22]. According to Kumar [23] reported the

increment in number of branches per plant might be role of P in cell division activity, leading to the increase of plant height and number of branches and consequently increased the plant dry weight. Application of small amounts of P fertilizer dramatically increased nodulation, N accumulation and seed yields of haricot bean and common bean [24].

According to Sarker [25] lentil yields at the farm level are far below the genetic potential of its cultivars. Unavailability of the tested site-specific lentil cultivars and imbalanced use of fertilizers could be the contributing factors towards these lower yields. Most of the soils under lentil cultivation are low-to-medium in available phosphorus, therefore they respond positively to P-fertilizer application [26]. Further, improvement in the genotypes would be helpful to get the highest response from lower-P soils. The differences in genotypes to grow in P limited soils have been reported in several crops such as common bean [27], haricot bean [21] and faba bean [16] which may be due to differences in changing rhizosphere pH, release of organic compounds, root surface area [28], production and secretion of phosphatase enzymes by the roots [29] and use of acquired P in dry matter production [30].

Phosphorus contributes substantially to increased yield of legumes by enhancing the physiological functions of the crop plants, root development, and nodulation [31]. Phosphorus application not only increases the dry matter and seed yield of lentil but also enhances the N and P content of the seed by increasing nodulation and root development [32]. However, no studies have been conducted on response of improved lentil varieties to phosphorus fertilizer application in the Ambo area. In general, blanket recommendations, regardless of considering the physical and chemical properties of the soil would not lead to increase the crop productivity in the country. Hence, the yield potentials of newly developed lentil varieties with different phosphorus rates is needed in order to explore the varieties potential in maximizing lentil yield in the area and to identify better yielding lentil varieties for the area. This apart, there is scanty information on the optimum phosphorus level for lentil production in the area. Therefore, the objective is to evaluate the performance of lentil varieties to phosphorus rates in terms of growth parameters, yield and its components and nodulation under rain-fed vertisol conditions of Ethiopia.

Material and Methods

Description of experimental site

The experiment was conducted in 2016 cropping season at Ambo University main campus research farm which located at a latitude 9°11'0" North and longitude 38°20'0" East with an altitude of 1980 m.a.s.l. The mean annual rainfall was 942 mm with unimodal distribution. The mean annual minimum and maximum temperatures were 8.25 and 23.4°C, respectively.

Experimental treatments and procedures

The field experiment comprised three improved lentil varieties [Teshale (FLIP 96-46L), Alemtena (FLIP 96-49L), Gudo (Flip 84-78L) and one local variety (EL-142)] and four levels of phosphorus rates (0, 10, 20 and 30 kg P ha⁻¹) were used. The design of the experiment was randomized complete block design in 4 × 4 factorial arrangements with three replications. Four lentil varieties were used as Factor A and four phosphorus rates as Factor B.

Soil sampling and analysis

Pre-planting and post-harvest soil samples (0-20 cm depth) were collected from five spots diagonally and composited. Composited soil sample was prepared following standard procedures and analyzed for soil pH, organic matter, total nitrogen, available phosphorus and cation exchange capacity (CEC). After harvest, soil samples were also collected from each plot and composited treatment wise for the determination of phosphorus. Particle size distribution determination was following [33] procedure.

Soil pH was determined at 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter. Based on the oxidation of organic carbon with acid potassium dichromate, organic matter was determined using wet digestion method and total nitrogen using Kjeldhal method as described by Olsen [34]. Besides, available phosphorus was determined according to Olsen method [35]. CEC was determined by measuring the total amount of cation needed to replace all the cation from the soil exchange site and expressed in Cent mole per 100-gram soil (Cmol/100 g soil) [36].

Experimental procedures

Cleaned seeds of lentil varieties were used for planting. The field was prepared with conventional methods using oxen plough. Planting of lentil varieties were done in last week of July 2016 cropping season. The phosphorus fertilizer rate was calculated and applied per plots. The recommended nitrogen fertilizer rate (18 kg N ha⁻¹) as starter was applied once at planting for the area. The source of nitrogen and phosphorus was urea and TSP. The recommended seed rate 100 kg ha⁻¹ was used.

Improved agronomic management practices were applied to lentil varieties as per research recommendations. The plot size was 2.1 m × 3 m=6.3 m² accommodating seven rows of plants spaced at 30 cm between rows and 10 cm between plants. Lentil varieties were harvested at maturity. The harvested plants were sun dried for 7-10 days and then hand shelled. All necessary agronomic practices as required by the crop were carried out as per the research recommendation for lentil production.

Plant tissue and seed collection and analysis

After maturity of lentil, net plot was harvested at ground level and air dried and partitioned in to straw and grain. The straw and grain samples were analyzed for P concentrations from which P uptake in straw and grain were calculated by multiplying P content with respective straw and grain yield/ha. Total P uptake, by whole biomass was obtained by summing up the P uptakes by grains and straw

Total P analysis of grain and straw at maturity were carried out on the plant sampled for grain and biological yield determination at harvest [37]. Plant samples were composited treatment-wise from three replications. Phosphorus contents in lentil grain and straw were determined by taking 1.0 g of dried ground sample in a digestion tube. Concentrated HNO₃ (10 mL) was added to the tube followed by the addition of 5 mL of concentrated HClO₄ (70%). The ingredients were digested in a digester until the colors cleared up. The digested material was diluted to 25 mL volume using distilled-deionized water [38]. For P estimation, 1.0 ml of digested material was taken into a 10 mL tube. Aqueous 2M HNO₃ solution (2 mL) was added and the mixture was diluted to 8 mL with distilled water. Thereafter, 1 ml of ammonium molybdate-ammonium vanadate solution was added and the volume

was made to 10 mL with distilled water. The tube was shaken and allowed to stand for 30 minutes. The absorbance was measured by colorimeter at 430 nm and was compared with the absorbance of standard phosphorus curve. Phosphorus content in the plant tissue was determined colorimetrically by vanado-molybdate method [36].

Plant P uptake and use efficiencies

Nutrient use efficiency (NUE) is a measure of how well plants use the available mineral nutrients. It can be defined as yield (biomass) per unit input (fertilizer, nutrient content). Improvement of NUE is an essential pre-requisite for expansion of crop production into marginal lands with low nutrient availability but also a way to reduce use of inorganic fertilizer. Usually P use efficiency of various crops is known to be low and recovery in the year of application varying between 15-25% [39] because of high fixation capacity of the soil. The various reactions of applied P in the soil resulting in formation of compounds that become less available to plants are considered as one of the factors attributing to low P recovery [40]. Because of the substantial residual effect of P fertilization on the P nutrition of future crops, first year recovery of P by the crop will usually greatly underestimate P use efficiency [41]. Total P uptake, by above ground biomass was calculated by summing up the P uptake by grains and straw.

Apparent fertilizer P recovery was calculated as described by [42]:

$$AFR = \frac{(Un - Uo)}{n} \times 100$$

Where, AFR=apparent fertilizer recovery; Un=nutrient uptake at "n" rate of fertilizer and Uo=nutrient uptake by control (no fertilizer nutrient).

Agronomic and physiological P use efficiencies were calculated by using procedures described by [43] as:

$$AE = \frac{(Gn - Go)}{n}$$

$$PE = \frac{(Gn - Go)}{(Un - Uo)}$$

Where, AE=agronomic efficiency; PE=physiological efficiency; Gn and Go stand for grain yield of the plots fertilized at "n" rates of fertilizer and grain yield of unfertilized, respectively. Un and Uo stand for nutrient uptake at "n" rate of fertilizer and uptake at control, respectively.

P uptake of seed=P concentration of seed/ 100*seed yield (kg/ha)

P uptake of straw=P concentration of straw/ 100*straw yield (kg/ha)

TPU=P uptake of grain+P uptake of straw, where TPU, total phosphorus uptake

Data collected

All important growth and yield parameters were collected following the standard procedure for the crop such as days to 50% emergency, days to 50% flowering, number of nodules/plant, volume of the nodules, Nodule dry weight (gm/plot), days to 95% maturity, plant height (cm), primary branches per plant, secondary branches per plant, pods per plant, seed per pod, thousand seed weight, grain yield, dry biomass yields and harvest index; which was determined by the following formula and expressed in percentage (%):

$$H.I = \frac{EconomicYield}{BiologicalYield} \times 100$$

Statistical analysis

The collected data were subjected to the analysis of variance (ANOVA) using statistical computer software SAS 9.0 [44]. Mean separation was done using least significance difference (LSD) procedure at 5 % probability level

Economic analysis

For partial budget and marginal rate of return analysis, lentil grain yield was valued at an average open market price of EB 35 kg⁻¹ and Triple superphosphate (TSP) fertilizer cost was EB 21 kg⁻¹. Seed yield was down adjusted at 10 % [45].

Results and Discussion

Physical and chemical properties of soil in the experimental site

The particle size distribution of the soil is clay with (3% sand, 10% silt and 87% clay). The soil pH was 7.4-7.8 which is slightly alkaline [46]. Lentil has been found to do well at pH values of 7.61 however; lentils grow best at a soil pH of 6.0 to 8.0 so that the soil pH is ideal for lentil production. The soil organic carbon content was 1.53%. Similarly, total nitrogen of 0.04%, CEC of 26.67 cmol (+) kg⁻¹ and total available phosphorus of 45.31 ppm (Table 1). The soil of the experimental site has high organic carbon content, very low total N, medium CEC and high in available P [46] and [47] (Table 1).

pH (H ₂ O) (1:2.5)	OC (%)	TN (%)	CEC(cmol(+)/kg)	TAP (ppm)	Texture
7.61	1.53	0.04	26.67	45.31	
Slightly alkaline	High	Very low	Medium	High	Clay

Table 1: Pre-planting soil physicochemical analysis result of the study area. OM=Organic Matter; TN=Total Nitrogen; TAP=Total Available Phosphorus; CEC=Cation Exchange Capacity.

Phenological and nodule parameters of lentil

The mean days to 50% emergence is indicated in Table 2. The main effect of Phosphorus application rates was significant (P<0.05) affected days to emergence of lentil, while the main effect of varieties and their interaction were not significant (Table 2). The days to 50% emergence were 5 for all lentil varieties. In contrary, Number of days to emergence was significantly affected by different in common bean varieties [48] and also among chick pea varieties [49]. The number of days to 50% emergence varied from 4.42 to 5.0 among applied phosphorus rates. Similarly, result was reported by [50]. The probable reason might be that applied phosphorus supply played an essential role in plant emergence.

Varieties	Days to emergency	Days to maturity	Nodule volume(ml)	Nodule dry weight (g)	Number of primary branches	Number of secondary branches
Gudo	4.83	121a	0.195	0.079	8	11
Alemtena	4.67	120a	0.216	0.093	9	11
Teshale	4.5	116b	0.225	0.087	9	12
EL-142	4.58	114b	0.226	0.088	9	13
LSD (0.05)	Ns	4.08	Ns	Ns	Ns	Ns
Phosphorus rates (P kg ha⁻¹)						
0	5.00a	135a	0.104c	0.048b	7c	8c
10	4.67a	118b	0.187b	0.09a	8cb	11b
20	4.50b	114b	0.269a	0.103a	9b	13a
30	4.42b	104c	0.304a	0.105a	11a	14a
LSD (0.05)	0.34	4.08	0.046	0.022	1.25	1.52
CV (%)	8.78	4.18	25.75	30.6	17.06	15.72

Table 2: The main effect of varieties and phosphorus rates on days to emergency, days to maturity, nodule volume and dry weight and growth parameters of lentil. Means within the same column followed by the same letter are not significantly different at 5% probability level, Ns=Non-significant difference at 5% probability level. LSD: Least Significant Difference; CV: Coefficient of Variation.

The physiological maturity of lentil was highly significant ($P < 0.01$) due to by the main effect of lentil varieties and phosphorus rates, while their interaction effect was not significant (Table 2). Variety Gudo (121) and Alemtena (120) matured late as compared to other varieties (Table 2). This might be due to the inherent genetic difference among the varieties of lentil and variability in phenological characteristics. Similarly, [51] reported that high variability was observed among genotypes tested for days to flowering, maturity and grain filling period.

The shortest days (104) to physiological maturity was obtained with application of 30 kg ha⁻¹ and the longest days (135) obtained from control plots. The probable reason might be that phosphorus hastens maturity of plant. Similarly, Brady [52] reported that phosphorus application could possibly shorten maturity since it promotes rapid cell division. Likewise, Onasanya [53] reported that phosphorus plays an important role in many physiological processes that occur within a developing and maturing plant, it is involve in enzymatic reactions in the plant and it is also hastens the ripening of fruits thus counteracting the effect of excess nitrogen application to the soil.

The days to 50% flowering of lentil was highly significant ($P < 0.01$) due to the main effect of varieties of lentil, phosphorus rates, and their interaction effect (Table 2). The longest numbers of days to 50% flowering (68) were recorded at control for all varieties and the shortest number of days to flowering (51) were recorded at 20 kg P ha⁻¹ for all variety (Table 2). Application of P rates were varied the number of days to flowering between 51 and 68 on lentil varieties.

Nodule volume and nodule dry weight

The nodule volume and nodule dry weight was highly significantly ($P < 0.01$) the main effect of phosphorus rates while the main effect of varieties and their interaction effect were not significant (Table 2).

Significantly higher nodule volume (0.304 ml) was recorded with application of 30 kg P ha⁻¹ followed by 20 kg P ha⁻¹ (0.269 ml) while the lowest nodule volume (0.104 ml) was recorded from control. Increasing P levels from 0 to 30 kg P ha⁻¹ significantly increased nodule volume by about 192% and showed consistent increment. When the rate of phosphorus was increased from 0 to 10 kg P ha⁻¹, the nodule volume was increased by 63%, 44% with increased phosphorus from 10 to 20 kg P ha⁻¹ and 13% from 20 to 30 kg P ha⁻¹, which indicates beyond the optimum phosphorus rate decreasing of nodule volume (Table 2).

The result was consistent with the findings [54] nodule volume can be increased by treating phosphorous deficient soils with fertilizer phosphorous.

Significantly higher mean nodule dry weights (0.105 g) was recorded from the application of 30 kg P ha⁻¹ and the lowest nodule dry weights (0.048) was from the control treatment (Table 2). Nodule dry weight was increased by 115% and 119% due to application of 20 and 30 kg P ha⁻¹ as compared to the control treatments, respectively. Consistent increment of nodule dry weights was recorded as P rate increased from 0 to 30 kg P ha⁻¹, the possible reason for higher nodule dry weights at the highest phosphorus rate could be due to increased root nodule production which resulted on more nodule dry weights. Similarly, Nkaa [55] who reported that phosphorus fertilizer application significantly enhanced nodule dry weight of cowpea.

Growth parameters

The numbers of primary and secondary branches per plant was significant ($P < 0.01$) due to the main effect of phosphorus rates while the main effects of varieties and the interaction effect were non-significant (Table 2). Similarly, Zahan [56] indicated that lentil varieties did not show significant difference for number of branches. In

contrary, Sarker [57] reported that high variability in the number of branches in lentil cultivars.

Significantly lower (7) and higher (11) number of primary branches per plant were recorded in control and application of 20 kg P ha⁻¹ (Table 2). The mean number of primary branches per plant was increased by 14%, 22% and 44% for 10, 20 and 30 kg P ha⁻¹, respectively as compared control (Table 2). This may probably be due to the effect of phosphorus on the processes of cell division and balanced nutrition. Similarly, Haque [58] reported that the number of primary and secondary branches per plant was increased with increasing the level of nutrient.

Number of secondary branches per plant was significantly increased with the increase in applied phosphorus rates from control to 30 kg P ha⁻¹ (Table 2). The highest number of secondary branches per plant (14) was recorded with application of 30 kg P ha⁻¹ and the lowest number of secondary branches per plant (8) was recorded from the control. The mean secondary branches were increased by 42%, 62% and 79% under 10, 20 and 30 kg P ha⁻¹, respectively as compared to control (Table 2). This may probably be due to the effect of phosphorus on the processes of cell division and balanced nutrition. Similarly, Guriqbal et al. [58] reported that secondary branches per plants were increasing with increasing the level of nutrient. In contrary, Azmera [21] reported the number of branches per plant decreased with increasing phosphorus doses. The highest number of branches per plant was recorded from control.

Generally, the trend was uniform for all the varieties. This probable due to applied phosphorus played an essential role in hastening plant growth and development. Similarly, Tesfahun Woldesellase [59] who reported that fertilized lentil plants flowered five days earlier than those that were not fertilized. Likewise, phosphorus application could possibly shorten flowering days since it promotes rapid cell division reported by Tessema Tesfaye and Alemayehu Balcha [60].

Nodule number

The number nodule plant-1 of lentil was indicated in Table 3A. The main effect of varieties, phosphorus rates and their interaction were significantly (P<0.05) affected number of nodule per plant (Table 3A). The highest number of nodules per plant (48) was recorded with application of 20 kg P ha⁻¹ on Gudo variety and least number of nodules per plant (19) was also on Gudo variety with no phosphorus application (Table 3B). The numbers of nodule per plant increased as phosphorus rate increases for all varieties. This might be due to application of phosphorus rate to plants enhanced the availability of essential elements for plant nutrition.

Phosphorus rate (PR) kg ha ⁻¹	Varieties (V)				
	Gudo	Alemtena	Teshale	EL-142	Mean
0	68a	68a	68a	68a	68
10	53c	54c	53c	62b	56
20	51c	51c	51c	51c	51
30	62b	62b	62b	68a	64
Mean	59	59	59	62	
LSD (0.05) V *PR=4.23					

Variety=0.668	
Phosphorus rate=0.668	
CV (%) 4.39	

Table 3A: Interaction effect of varieties and phosphorus rates and on days to 50% flowering of lentil at Ambo 2016. Means within the same column followed by the same letter are not significantly different at 5% probability level. LSD: Least Significant Difference; CV: Coefficient of Variation.

The application of phosphorus rates beyond 20 kg P ha⁻¹ resulted in decreased number of nodule per plant for all the varieties. Similarly, Taylor [61] reported increased number of nodules per plant due to phosphorus application. During nodulation, P is an essential ingredient for Rhizobium bacteria to convert atmospheric N₂ into an ammonium (NH₄⁺) form usable by plants. Inadequate phosphorus restricts root growth, the process of photosynthesis, translocation of sugars and other such functions which directly influence N fixation by legume plants. Similarly, phosphorus fertilizer application was reported to significantly enhanced nodule number in cowpea [55]. Rahman [62] also reported that varieties significantly affect the growth, development and yield of lentil.

Phosphorus Rate (PR) (kg ha ⁻¹)	Varieties (V)				
	Gudo	Alemtena	Teshale	EL-142	Mean
0	19h	21gh	23ghef	24ghefd	22
10	22ghf	25ghefd	27gcefd	29cefd	26
20	48a	29cebd	32cb	36b	36
30	29cebd	24ghef	31cbd	25ghefd	27
Mean	30	25	28	28	
LSD (0.05) PR XV=6.68					
Variety=18.06					
Phosphorus rate=3.56					
CV (%) 14.45					

Table 3B: Interaction effect of phosphorus rates and varieties on number of nodules per plant of lentil at Ambo in 2016. Means within the same column followed by the same letter are not significantly different at 5% probability level. LSD: Least Significant Difference; CV: Coefficient of Variation.

Plant height

The plant height of lentil was significantly (P<0.01) affected by the interaction effects of varieties and phosphorus rates (Table 4). Significantly taller plant height (49 cm) was obtained on Teshale variety with the application of 20 kg P ha⁻¹, while the shorter plant (35) was recorded on variety Gudo without Phosphorus application (Table 4). Plant height was increased as rate of P applied increased from the control consistently up to the maximum rate. The application of 20 kg

P ha⁻¹ gave significantly taller plants to other P rates for all the varieties (Table 4). Increased in plant height with the increase in rate of P might be due to phosphorus fertilizer contribution to availability of soil nutrients which increases their uptake by plants. Likewise, Tekle [16] described that phosphorus application that facilitated better absorption of soil moisture and nutrients resulting in taller plant height of faba bean in comparison with no phosphorus application.

Phosphorus rate (PR) kg ha ⁻¹	Varieties(V)				
	Gudo	Alemtena	Teshale	EL-142	Mean
0	35g	41edc	37efg	36efg	37
10	38efg	45bac	43bcd	39efdg	42
20	41efdc	47ba	49a	48ba	46
30	36fg	38efg	45bac	45bac	41
Mean	37	48	44	42	
LSD (0.05) PRs × V=4.88					
Variety=2.40					
Phosphorus rate=2.40					
CV (%) 7.06					

Table 4: Interaction effect of phosphorus rates and varieties on plant height of Lentil at Ambo in 2016. Means within the same column

Treatments	Number pods per plant	Number of seeds per pod	Seed yield (kg ha ⁻¹)	Thousand seed weights(g)	Harvest index (%)
Varieties					
Gudo	102	1	1925	29b	45ba
Alemtena	112	1.5	2024	31ba	47a
Teshale	124	1.42	1907	32a	46ba
EL-142	110	1.42	1908	30ba	42b
LSD (0.05)	Ns	Ns	Ns	2.44	4.44
Phosphorus Rates (kg ha⁻¹)					
0	66d	1c	1509c	29c	42b
10	101c	1c	2044ba	34b	45b
20	130b	2a	2360a	37a	42b
30	150a	2a	1852b	24d	51a
LSD (0.05)	18.06	0.317	336	2.44	4.44
CV (%)	19.44	26.56	20.81	9.54	11.77

Table 5: The effect of lentil varieties and phosphorous rates on number of pod per plant, seed per pod, grain yield, thousand seed weights and harvest index of lentil at Ambo in 2016. Means within the same column followed by the same letter are not significantly different at 5% probability level, NS=Non-significant difference. LSD: Least Significant Difference; CV: Coefficient of Variation.

The number of pods per plant was significantly (P<0.05) affected by application different rates of phosphorus. Significantly lower number of pods 66 was found from control. Significantly higher number of pods per plant (150) was recorded with the application of 30 kg P ha⁻¹.

followed by the same letter are not significantly different at 5% probability level. LSD: Least Significant Difference; CV: Coefficient of Variation.

Increase in plant height of lentil varieties as increases phosphorus rates. Similarly, [63] reported that plant height was linearly increased with increasing level of fertilizer. Ullah [17] reported that difference in plant height could be due to variation in genetic make-up or the hormonal balance and cell division rate that result in changes in the plant height of the different varieties.

Yield and yield components

The number of pods per plant and number of seeds per pod were non-significantly (P<0.01) affected by the main effect of varieties of lentil, while the number of pods per plant and seeds per pod was affected by the main effect of phosphorus rates (Table 5). Teshale variety recorded the maximum (124) pods per plant and the minimum (102) pod per plant was obtained from Gudo Variety. Teshale, Alemtena and EL 142 Varieties were not statistically different from each other. Genotypic variation played significant role in producing pods per plant. Similarly Mohammadjanloo [64] and Rahman [65] reported that variation for number of pods per plant among various lentil varieties.

When compared to the control, the mean number of pods per plant was increased by 129% (Table 5). The trend indicated consistent increment in number of pods per plant with increment of phosphorus fertilizer application rates from control to 30 kg P ha⁻¹. This could be

attributed to the role of P fertilizer in ensuring availability of other plant nutrients which stimulated the plants to produce more pods per plant as phosphorus encourages flowering and fruiting. Likewise, Ullah [17]; Chiezey reported that increasing the rate of phosphorus increased the number of pods per plant and number of seed per pod. It appears that the availability of nutrient by increasing the level of phosphorus increased the number of seeds. Higher doses of chemical fertilizer were effective on mature pods plant-1 and number of seed pod-1 [66].

The number of seeds per pod was non-significantly different among the three varieties (Table 5). The highest (1.5) number of seed per pod was recorded with Alemtena. This might be due to the genetic make-up of the varieties. In contrary, Sharar [67] who had reported significant genotypic variation in the varieties of lentil for production of seeds per pod and number of pod per plant. Number of seed per pod was significantly affected by different rate of P applications.

Significantly higher (2) number of seeds per pod was recorded from application of 30 kg P ha⁻¹. Similarly, Shubhashree [68] reported application nutrient to permit development of more number of pods per plant and seeds per pod of lentils. Likewise, Ziedan [69] reported that increasing the rate of phosphorus increased the number of seeds per pod. It appears that the availability of nutrient by increasing the level of phosphorus increased the number of seeds. This result is in line with Sardar [66] who reported that higher doses of chemical fertilizer were effective on number of seed pod-1.

Seed yield

Seed yield is one of the most important and phenomenal yield components which describe the overall potential of the genotypes and response to treatments applied. The seed yield of lentil was significantly (P<0.01) affected by main effects phosphorus rates but non-significant for varieties and their interaction (Table 5). In contrary, Edossa [3] reported high significant differences were observed among lentil genotypes for most yield related traits, grain and biomass yield and harvest index.

Significantly higher seed yield of lentil was produced with application of 20 kg P ha⁻¹ while the lowest seed yield was obtained from control (1509 kg ha⁻¹). This might be due to the importance of phosphorus in a number of metabolic functions and is especially important for grain formation [32]; therefore, its proper supply to the crops improves their yields. It is needed in relatively large amounts by legumes for growth and nitrogen fixation, and it was found to increase biomass, yield, nodulation, and nutritional quality in lentils [70]. The higher seed yield of lentil gave yield advantage of 56, 15 and 27% over control, application of 10 and 30 kg P ha⁻¹, respectively.

Enhanced seed yield of lentil by increasing P-levels was also reported by Kumar et al. [23]. Improved fertilization enhances the crop-grain yields due to increased availability and uptake of macro and micronutrients [54]. There was a trend of increasing seed yield ha⁻¹ between control to 20 kg P ha⁻¹ and seed yield start to decline after. Increased seed yield could be due to balanced nutrient supply which was higher when phosphorus was applied at the time of sowing and it enabled the plants to produce better growth and seed yield. Kumar et al. [23] reported that application of phosphorous improved the nutrient availability, resulting into greater uptake which might have increased the photosynthesis and translocation of assimilates to different parts for enhanced growth and yield of the crop. In later stage, more assimilates were produced than used in growth and

development and the excess assimilates were diverted to storage compounds resulting into increased seed yield. Likewise, Zafar et al. [71] reported that when phosphorus was applied at the time of sowing, it enabled the plants to produce better growth and seed yield.

Thousand seed weights

The main effects of variety and phosphorus rates was showed highly significant (P<0.01) difference on thousand seed weight while non-significant for their interaction effect (Table 5). Significantly higher thousand seed weight of (32 g) was recorded for variety Teshale and lower (29 g) for variety Gudo. Similarly, Singh et al. [72] reported significant difference for thousand seed weight among lentil genotypes. Significantly lower (29 g) and higher (37 g) 1000-seed weight were obtained from control and with application of 20 kg P ha⁻¹ respectively. Increase in 1000-seed weight might be due to the influence of cell division, phosphorus contents in the seed as well as the formation of fat and albumin. Thousand-seed weight of lentil also significantly increased with all levels of fertilizers compared to control [17].

Harvest index

Harvest index is the measure of physiological efficiency of a crop plant to convert photosynthesis into the economically important parts of the plant that is ratio of grain to above ground dry biomass are important indicators in seed yield [73]. The main effect of variety and phosphorus rates had highly significant (P<0.01) difference on harvest index while non-significant for their interactions (Table 5). Significantly higher mean values of harvest index (47%) was obtained from Alemtena lentil variety followed by Teshale (46%) and the lowest (42%) by EL-142 variety (Table 5). This result agreed with Hussain [74]; Shah et al.[75] who reported that all cultivars differed significantly from one another regarding to harvest index. Increased mean harvest index of lentil was obtained with increased application of phosphorus. The lower harvest index (42%) was recorded in control while higher harvest index (51%) was recorded with the application of 30 kg P ha⁻¹ (Table 5). This result was in consistence with [76] who reported that lower harvest index at low level of phosphorus application might be due to poor development of plants at different growth stages. Birhan Abdulkadir [77] reported a significant response of harvest index to the application of P on haricot bean. Additionally, the application of 46 kg P₂O₅ tended to improve the harvest index of faba bean when compared with no P application [16].

Straw yield

The mean dry straw yield of lentil is indicated in Table 6. Main effect of varieties and phosphorus rate showed highly significant (P<0.01) difference on dry biomass yield while their interaction effect was significant (Table 6). Significantly higher dry biomass yield (3874 kg ha⁻¹) was obtained from variety EL-142 with application of 20 kg P ha⁻¹, while the lowest (1695 kg ha⁻¹) was recorded for variety Gudo with application 30 kg P ha⁻¹ (Table 6). All applied phosphorus rates gave significantly higher dry biomass yield as compared to control (Table 6). Dry biomass yield increased as rate of P applied increased from the control to the 20 kg ha⁻¹ of p application and beyond 20 kg ha⁻¹ it declines.

Phosphorus Rate (PR) kg ha ⁻¹	Varieties (V)				
	Gudo	Alemtena	Teshale	EL-142	Mean

0	2250.0f eg	1756.7i	1855.7hi g	2119.7f hig	1995.5 3
10	2455.7f ed	2589.0c ed	2222.3f heg	2611.3c ed	2469.5 8
20	2786.7c bd	3222.6b	3016.7c b	3874.3a	3225.0 7
30	1694.7i	1708.3i	1745.7i	1775.7h i	1731.1
Mean	2296.78	2319.15	2210.1	2595.25	
LSD (0.05) PR × V=451.20					
Variety=238.16					
Phosphorus rates=238.16					
CV (%) 10.99					

Table 6: Interaction effect of phosphorus rates and varieties on biomass yield of lentil at Ambo in 2016. Means within the same column followed by the same letter are not significantly different at 5% probability level. LSD: Least Significant Difference; CV: Coefficient of Variation.

Mean dry biomass yield ranged from 1996 kg ha⁻¹ for the control to 3225 kg ha⁻¹ for 20 kg P ha⁻¹ application. Increased in dry biomass yield of lentil with the increased rate of P might be due to availability

of soil nutrients which increases their uptake by plants, which resulted in higher dry matter accumulation in leaves and stem at earlier growth stages and better translocation to seed during later stages. Similarly, Nkaa et al. [55] reported that increasing rate of phosphorus application increased dry matter of lentil. The increase in biomass yield by phosphorus application which may indicate the nutrients is playing a role in metabolism, chlorophyll formation and photosynthesis activities of the plant which in turn increase the biological yield [78].

The relationship between yield and yield attributes of lentil

The relationship among yield and yield components of lentil was presented in Table 7. Correlation analysis indicated that number of nodule per plant was significantly and negatively associated with days to emergency (Table 7). Days to emergency were significantly and negatively correlated with grain yield. The association between days to maturity and nodule number was weak and positively significant (0.46) and also days to maturity positively significant and strongly associated with nodule volume (0.70). Nodule volume was positively associated and highly significant with number of branches and number of seed per pod and significant with harvest index. Days to 50 % flowering showed positive and highly significant correlation with days to maturity. This finding agrees with the result reported by Alemayehu Dugassa et al. [51]. The number of pod per plant was strongly positive and significantly associated with number of primary and secondary branches (0.57 and 0.78) respectively, because the number of pods depends on capacity of branches to hold pods.

Plant character															
	DE	NNP	NV	NDW	DTF	PH	NPB	NSB	NPP	NSP	BMH	GYH	TSW	DTM	HI
DE		-0.12*	-0.33*	-0.33*	-0.29*	-0.01	-0.2	-0.11	-0.26	-0.14	-0.29*	-0.40*	-0.29*	0.25	-0.16
NNP			0.28	0.25**	0.22	0.21	0.24	0.35*	0.38**	0.28	0.43**	0.41**	0.29*	0.46**	0.04
NV				0.48**	0.03	0.24	0.38**	0.54**	0.6	0.47**	0.63**	0.31*	0.44**	0.70**	0.31*
NDW					0.09	0.11	0.16	0.42**	0.44**	0.25	0.37**	0.34*	0.38**	0.47**	0.04
DF						0.30*	0.08	0.19	0.24	0.14	0.28*	0.56**	0.48**	0.74**	-0.41**
PH							0.11	0.2	0.28*	0.12	0.39**	0.21**	0.14	0.28*	0.13
NPB								0.60**	0.57**	0.11	0.21	0.04*	0.34*	0.39**	0.21
NSB									0.78**	0.40**	0.59**	0.33*	0.46**	0.82**	0.23
NPP										0.55**	0.66**	0.29*	0.41**	0.75**	0.33*
NSP											-0.39**	0.07*	0.37**	0.52**	0.29*
BMH												0.61**	0.40**	0.75**	0.31*
GYH													0.43**	0.58**	0.55**
TSW														0.46**	0.04
DTM															-0.09
HI															

Table 7: Correlation (Pearson) analysis of yield and yield related parameters of lentil varieties grown in the field at Ambo in 2016. DTE=Days to Emergence; DTF=Days to 50% Flowering; DTM=Days to Physiological Maturity; NPB=Number of Primary Branches; NSB= Number of

Secondary Branches; PH=Plant Height; NNP=Number of Nodules per Plant; NV= Nodule Volume; NDW=Nodule Dry Weight; NPP=Number of Pod per Plant; NSP=Number of Seed per Pod; TSW=Hundred Seed Weight; GYH=Grain Yield per Hectare; BMH=Biological Yield per Hectare; HI=Harvest Index; *,**=Significant at 5% and 1% level of significance respectively.

The seed yield was positively correlated to all characters except day to emergency. The association between number of seed per pod with biomass yield was highly significant and negatively correlated. In line with this result, reported by Tigist Dejene [79] that seed yield was positively correlated with plant height, number of pods per plant and biomass yield. However, the authors noted that harvest index rather than biomass yield was a limiting factor in these legume species, and the correlation between the traits was negative. On the other hand, harvest index was found to be related positively with number of seeds per plant and seeds per pod [80]. Salado et al. [81] who reported that working in soybean, found highly and significantly negative association of harvest index with days to flowering.

Phosphorus uptake and allocation

The effects of applied P on seed and straw P level of the lentil varieties is presented in Table 8.

Considerable variation in P uptake and allocation were observed among the varieties of lentil due to different rates of applied phosphorus.

Grain phosphorus content increases with increased Phosphorus application from 0 to 30 kg ha⁻¹ and the higher (0.57%) grain p uptake was observed from variety Teshale and the lower (0.18%) from Alemtena and EL-142 varieties at 30 kg ha⁻¹, without phosphorus application (control) respectively. Similarly, [82] straw and grain p uptake increase with phosphorus fertilizer application. The lowest grain P uptake was observed from Alemtena and EL-142 varieties without P fertilizer application. Moreover, the positive effect of P application from 0 to 30 kg ha⁻¹ on the straw phosphorus content was higher (0.33%) in variety Alemtena whereas least in variety EL-142 from control plot (0.02%). Generally, all the varieties had different uptake and allocation for applied phosphorus. This appears to indicate that there is an inherent varietal difference in phosphorus uptake and thereby protein production. Similarly, Lentil variety differ in their root traits (root length and root-hair density), which influence the plant uptake of nutrients [83].

Variety Alemtena had higher phosphorus uptake in the application of 30 kg P ha⁻¹ phosphorus (Table 8), indicating its response for higher rates of phosphorus application particularly with respect to seed yield production. This is therefore, variety Alemtena was an efficient crop to higher rates of phosphorus application (30 kg ha⁻¹) and further application of higher P rates might have better efficiency and seed yield. Similarly, Machado and Furlani [84] who reported that the differences among crop varieties in their ability to absorb phosphorus from soils maybe due to at least three distinct root attributes; the physiological activity to absorb P from dilute solution; metabolic activity resulting in solubilization of absorbed P; and the ability of the root system to explore the soil phosphorus. Moreover, significantly lower phosphorus concentration in plant tissues that were not supplied with phosphorus fertilizer [59]. An increased trend in soil phosphorus content after harvest as compared to preplanting content of P was also observed in this study (Table 8).

Variety	P rate(kg/ha)	GP (%)	SP (%)	TPU(kg/ha)	SPH (%)
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Gudo	0	0.36	0.09	5.94	0.05
	10	0.37	0.09	8.6	0.12
	20	0.48	0.14	13.09	0.16
	30	0.49	0.16	16.13	0.23
	Mean	0.42	0.15	10.94	0.14
Alemtena	0	0.18	0.04	3.57	0.05
	10	0.2	0.05	4.37	0.17
	20	0.36	0.2	12.64	0.3
	30	0.49	0.33	22.49	0.32
	Mean	0.31	0.26	10.77	0.21
Teshale	0	0.45	0.03	6.68	0.06
	10	0.45	0.22	11.31	0.08
	20	0.52	0.17	14.64	0.21
	30	0.57	0.18	18.12	0.24
	Mean	0.5	0.15	12.69	0.15
EL-142	0	0.18	0.02	2.96	0.06
	10	0.29	0.1	6.39	0.17
	20	0.31	0.15	11.65	0.18
	30	0.32	0.18	13.39	0.27
	Mean	0.28	0.15	8.6	0.17

Table 8: The effect of phosphorus on grain and straw P content, total uptake and residual phosphorus content of the soil after harvest. GP=Grain Phosphorus content; SP=Straw Phosphorus content; TPU=Total P Uptake; SPH=Soil P content after Harvest.

Apparent phosphorus recovery and efficiency

In all lentil varieties, non-consistent values of apparent fertilizer recovery, agronomic efficiency and physiological efficiency were observed with increasing P rates (Table 9). Variety Alemtena with application of 30 kg P ha⁻¹ had the highest value of recovery (63 %) followed by Teshale (46 %) with application of 10 kg P ha⁻¹. The agronomic efficiency, Gudo variety with the application of 20 kg P ha⁻¹ was higher (50 %) followed by Teshale (40%) with at 20 kg P ha⁻¹ while 2.78 % EL-142 with application of 10 kg P ha⁻¹.

Variety	P rate(kg/ha)	AFR (%)	AE (%)	PE (%)
Gudo	10	26.62	50	187.97
	20	35.75	34.99	97.9
	30	33.98	39	114.49

	Mean	32.12	41.33	133.45
Alemtena	10	8.04	9.83	122.91
	20	45.36	22.14	48.82
	30	63.07	25.69	40.73
	Mean	38.82	19.22	70.82
Teshale	10	46.22	19.44	41.99
	20	39.78	40.28	101.2
	30	38.14	28.15	73.81
	Mean	41.38	29.29	72.33
EL-142	10	34.36	2.78	8.1
	20	43.47	29.72	68.41
	30	35	33.33	95.88
	Mean	37.61	21.94	57.46

Table 9: The effect of phosphorus on fertilizer recovery and efficiency on lentil varieties. AFR=Apparent Fertilizer Recovery; AE=Agronomic Efficiency and PE=Physiological Efficiency.

The mean physiological efficiency of Gudo variety with the application of 10 kg P ha⁻¹ had higher (188%) followed by Alemtena (123%) with application of 10 kg P ha⁻¹ and least from EL-142 (8.10) with 10 kg P ha⁻¹ application. This might be due the differences in phosphorus allocation of the varieties to their seeds and straw besides their uptake. Difference in P-use efficiency among crop species and genotypes within species including dry bean is widely reported by Fageria et al. [27]. Baligar et al. [85] reported that plants differ widely in their ability to grow in soils with low P, and this has been attributed to several plant traits, including morphology of root system and root hair density.

Effect of Phosphorus Fertilizer on Economic Feasibility of Lentil Production

The highest net benefit of EB 72240 ha⁻¹ with marginal rate of return of 1177% was obtained with application of 20kg P ha⁻¹ followed by net benefit of EB 62706 ha⁻¹ and marginal rate return of 1445% with application of 10 kg P ha⁻¹ and the lower net benefit was 55188 EB ha⁻¹ with marginal rate return 243% through application of 30kg P ha⁻¹(Table 10). This is agreement with the findings of [58]. Therefore, application of 20 kg P ha⁻¹ is economical feasible for lentil production in Ambo area which support the previous P fertilizer recommendation for pulses in the country.

	Phosphorous rate (kg P ha ⁻¹)			
	0	10	20	30
Average yield(kg/ha)	1509	2024	2360	1852
Adjusted yield(kg/ha)	1358	1822	2124	1667
Gross filed benefit(EB/ha)	47534	63756	74340	58338
Cost of fertilizer(EB/ha)	0	1050	2100	3150
Total cost(EB/ha)	0	1050	2100	3150

Net benefit (EB/ha)	47534	62706	72240	55188
Marginal rate of return (%)		1445	1177	243

Table 10: Partial budget Analysis on farm-lentil at Ambo Vertisol. Grain yield cost=35 EB kg⁻¹, Cost of UREA=11.92 EB kg⁻¹, Cost of TSP=21 EB kg⁻¹, Grain yield adjustment=10%.

Conclusion

The lentil varieties evaluated showed significant variation in some of the yield and yield parameters. Days to maturity, days to flowering, number of nodule, plant height, biological yield and phosphorus use efficiency were the most important characters in evaluating the performance of the varieties as these characters are highly determinant in economical view of crop production. Thus, the lentil varieties, as noticed from their performance on various growths and phenological characters including its response to phosphorus application, might be used alternatively under Ambo's agroecology. There was significance and positive correlation with most growth parameters, yield and yield components. Applications of phosphorus influenced all parameters of lentil varieties, P fertilizer recovery, agronomic and physiological efficiencies of the varieties. Application of P rates (20 kg/ha) was better in most parameters recorded hence it become decreasing if more than this or at 30 kg/ha of P was applied. Ultimately highest net benefits of EB 72240 ha⁻¹ and marginal rate return of 1177% with application of 20 kg P ha⁻¹ was obtained for lentil production. Therefore, production of lentil varieties with 20 kg P ha⁻¹ is recommended for vertisol of Ambo district and similar agroecology.

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