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Effect of Lime and Phosphorus on Yield and Yield Components of Groundnut Varieties [*Arachis hypogaea* L.] on Acidic Soil in Nedjo District, Western Ethiopia

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Abstract

Groundnut (*Arachis hypogaea* L.) is an important cash crop for smallholder farmers in western Ethiopia. However, the yield of the crop is very low mainly because of strong soil acidity and poor soil fertility management. A study conducted to evaluate the effect of lime and mineral phosphorus fertilizer on yield components and yield of groundnut. The treatments consisted of three phosphorus rates (0, 46 and 92 kg $P_2O_5 \cdot ha^{-1}$), three lime rates (0, 6, and 11 ton lime·ha^{-1}), and three groundnut varieties (local cultivar, Werer-961, and Werer-963) was laid-out as a randomized complete design in a factorial arrangement with three replications. The corresponding rates of phosphorus applied per pot of soil (7 kg) amounted to 0, 107 and 215 mg kg·$soil^{-1}$ and those of lime amounted to 0, 14, and 26 g kg·$soil^{-1}$. The analysis of variance showed that phenological characters, yield, and yield components significantly affected by interaction of variety, phosphorus, and lime. The highest dry pod yield produced by Werer-963 (2 kg dry pod yield·pot^{-1}) in response to the application 11 t·ha^{-1} lime and 46 kg $P_2O_5 \cdot ha^{-1}$. However, Werer-961 produced medium (1.5 kg dry pod yield·pot^{-1}) at 11 t·ha^{-1} lime and 92 kg $P_2O_5 \cdot ha^{-1}$ and the local cultivar produced minimum (1 kg dry pod yield·pot^{-1}) at the application of 11 t·ha^{-1} lime and 92 kg $P_2O_5 \cdot ha^{-1}$. In terms of phosphorus yield efficiency index, Werer-963 was highly efficient (index of 1.71), and Werer-961 was moderately efficient (index of 0.6). However, the local cultivar was inefficient (index of 0.04). It is at, in acidic soil of the study area Werer-963 is the best to be cultivated with application of lime 11 t·ha^{-1} and 46 kg $P_2O_5 \cdot ha^{-1}$ fertilizer, followed by Werer-961. The results of this pot experiment have revealed that farmers in the study area need to switch to cultivating the improved varieties of groundnut rather than local variety with the application of high rates of lime and moderate amounts of phosphorus.

Keywords

Dry Biomass Yield, Dry Pod Yield, Harvest Index, Yield Efficiency Index, Hundred Seed Weight

1. Introduction

Groundnut is an important cash crop for smallholder framers in Ethiopia. The crop covers about 41761.12 ha in the country [1]. Annual groundnut production in Ethiopia amounted 145191.45, the Oromia Region contributing about 59.2% to the total production and western Wollega Zone accounting for about 15% [2]. The land allotted for groundnut production in western Wollega was about 66.5 ha [3].

Groundnut production is expanding in western Ethiopia for improving livelihoods of farmers and traders since the crop has a huge potential of about 40% as a cash and food security crop [4]. However, the productivity of the crop is very low due to strong soil acidity and low phosphorus availability. Acid soils limit crop yields where food production is critical [5]. These constraints are the main causes for low dry pod yields of the crop in the study areas. However, farmers continue growing the crop in spite of obtaining low yields, since the crop is vital for meeting their nutritional and economic need. The dry pod yield of groundnut obtained from the acidic soil of western Ethiopia is 0.8 $t \cdot ha^{-1}$ [6], which is very low. However, the dry pod yield of groundnut on farmers' field, which is 1.73 $t \cdot ha^{-1}$ is lower than the dry pod yield of 1.80 - 2.50 $t \cdot ha^{-1}$ recorded at research field under rain-fed condition [1] and even may reach 6 $t \cdot ha^{-1}$ according to [7] as cited by Amare *et al.* [8]. This large gap between actual and potential yields is due to poor soil fertility, lack of improved varieties and no conclusive fertilizer recommendations are available. EARO [9] reported poor soil fertility management and inappropriate crop management as the main problems limiting production of groundnut. However, low soil fertility is the main abiotic stresses constraining groundnut production in Ethiopia particularly in western Ethiopia. Acid soils are deficit in several essential nutrient elements like P, Ca, and Mg critical for successful groundnut production. Liming is one of the potential options that increase soil pH; favoring the availability of nutrients like P, Ca, Mg, B, and Mo [10]. From different reports, application of lime and phosphorus on acid soil has beneficial effect on groundnut production. [11] reported application of both lime and phosphorus lowered significantly Aluminum and Iron.

In some highland of western Ethiopia like Gida Ayana, Jimma and West Wollega Zone, the available soil phosphorus has become deficient due to soil acidity. This problem has resulted in stunted growth and reduced yield of crops [12]. One of the benefits of phosphorus application through lime is improved growth and yield as shown by [13] especially when applied in combination with lime. Liming also enhanced availability of soil phosphorus for improved plant growth and increased the availability of nitrogen by hastening decomposition of organic matter [14]. Through liming acid soil, nutrient utilization efficiency and yield is increased as a result resource poor farmers under nutrient deficiency were improved [15]. Phosphorus utilization efficiency of high yielding crop varieties that are responsive to the nutrient is low under acidic soil condition, due to various soil factors like soil moisture and available nutrients [16].

Most groundnut varieties released in Ethiopia have potential to yield above 3 $tons \cdot ha^{-1}$, yet the average yield for groundnuts in Ethiopia is around 1 $tons \cdot ha^{-1}$ [17]. This indicates that there is big difference between the mean level of productivity of farmers and the yield per hectare of the different varieties of groundnut released at different times. To date, most of the research done on groundnut in the country is mainly on the development of improved varieties [18]. However, in western Wollega there is constraint of low soil fertility and lack of fertilizer recommendation for groundnut as one of the major production constraints in the country has remained one of the greatest impediments to bridging the gap between potential and harvested yields. However, some farmers used to apply 100 kg urea and 100 kg DAP per hectare without scientific contemplation [19]. However, research results from different regions of groundnut growing areas showed the possibility of improving groundnut productivity through appropriate rate fertilizers [20]. Report on the role of phosphorus fertilizer is improved growth, yield, and quality of groundnut. However, soil acidity becomes a major threat to crop production in western Wollega [5]. This is because it limits the availability of nutrients like phosphorus the contents of organic matter and nutrients in the soil are being depleted due to the soil acidity-associated problems [21]. The soils of the studied area are strongly acidic soil resulted in severe yield reductions [22]. As a result, farmers have been shifting toward production of relatively acid tolerant crops such as maize and sorghum. However, low to moderate (200 to 1000 kg $CaCO_3 \cdot ha^{-1}$) dose of lime applied along with phosphorus fertilizer in acid soils raise the soil pH besides increasing nutrient availability and reducing Al and Fe toxicity to increase groundnut productivity [23].

To reverse the situation improved the soil fertility management through liming and developing appropriate application of fertilizer is necessary to enhance the productivity of groundnut. Generally, in western Ethiopia, where groundnut is an oil crop and supporter of livelihood, it is important to improve its productivity through agronomic interventions. In view of this, there is a need to come up with application of phosphorus fertilizer and liming that will enable the farmers to cultivate the crop on profitable and sustainable basis. Therefore, it was hypothesized that application of phosphorus and lime increases yields of various groundnut varieties. It was also hypothesized that groundnut varieties differ in their response to phosphorus and lime applications rate. Thus, the objective of the study was to evaluate lime and phosphorus on yield and yield components of groundnut varieties (*Arachis hypogaea* L.) on acidic soil in Nedjo District, Western Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

A pot experiment was conducted at Nedjo Agricultural Technical Vocation and Education Training College (ATVET), which is located in western Wollega Zone of the Oromia Regional State in Ethiopia. Nedjo town is located at the distance of 186 km west of Nekemet town in western Ethiopia, which is in turn located at the distance of about 515 km from the capital, Addis Ababa in the westerly direction. The area known for its mixed cropping system.The study was conducted in 2019 during the rainy season. The area is geographically located at 9˚30'N latitude and 35˚30'E longitude and at the altitude of 1735 meters above sea level. The rainfall distribution of Nedjo is mono-modal with the long rain falling from April to October (**Figure 1**).

The annual rainfall during the experimental period was 1386 mm with mean minimum and maximum temperatures of 12˚C and 26˚C, respectively [24]. The soil is strongly acidic (pH 4.45), well-drained, deep, and reddish brown in colour and is in the category of oxisol [25] (**Figure 2**).

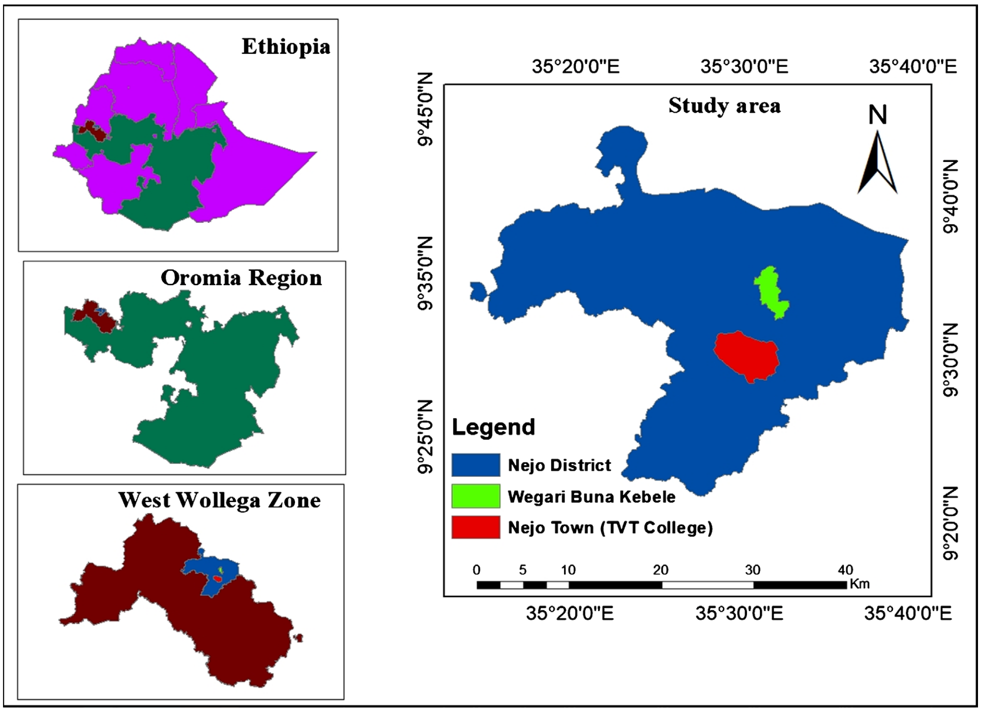

Figure 1. MAP of the study area western Ethiopia and experimental site.

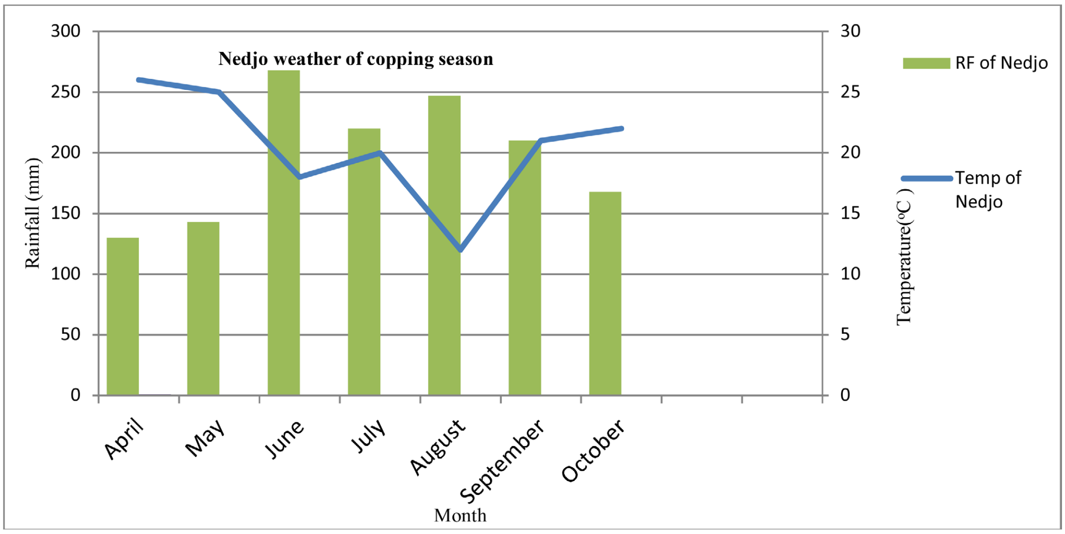

Figure 2. Rainfall distribution and temperature data of the experimental area of Nedjo during the 2019/20 cropping season, west Wollega Zone, Ethiopia.

Table 1. Varieties used for the study.

S. No	Name of variety	Year of release	Ecological requirement		Growth habit	Days to flowering	Days to mature	Yield t·ha^{-1}
			Rain fall	Altitude				
1	Werer-963	2004	569 - 1100 mm	750 - 1650	Bunch type	46	129	2.2
2	Werer-961	2004	569 - 1100 mm	750 - 1650	Bunch type	52	130	2.1
3	Kotote verity				Runner			0.6

Source: Ministry of Agricultural and Natural Resource [26].

2.3. Description of Planting Materials

As shown Table 1, two improved groundnut varieties and one local cultivar known as kotote were evaluated for their response to phosphorus and lime application. The improved varieties included Werer-961 and Werer-963 varieties, which have a bunch type growth habit [26].

2.3. Description of Fertilizer and Lime Material

TSP (Triple super phosphate), which contains 46% P_2O_5, was used as source of phosphorus. Calcium carbonate ($CaCO_3$) was used as a source of lime. The liming material had a purity of 93.7% [12].

2.4. Description of the Pot Experiments

The pots used for this experiment were made of polyethylene and each pot had a diameter of 40 cm and a height of 60 cm. Each pot had the capacity to hold 7.0 kg soil.

2.5. Collecting Soil for the Experiment

Soil was collected for the pot study from Wegari Buna kebele located near Nedjo town. The soil of Wegari Buna kebele is well-drained, deep, and reddish brown in colour. The sample was collected from the cultivated land and which was not lime applied previously. The samples were collected to the depth of 20 cm. About 500 kg soil was dug out from the cultivated land. The soil samples collected from different randomly identified spots in field were mixed thoroughly to make a homogenous composite sample.

2.6. Incubation

One kg of soil was treated with different rates of lime (0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10,000 and 11,000 mg of calcium carbonate) in triplicates and placed in polythene bags. Each polyethylene bags filled with the soil-lime mixture was tied up to avoid rapid evaporation of the water from the soil. Incubation was conducted in the laboratory at room temperature (25˚C) for one month. After the incubation period, soil pH and cation exchange capacity (CEC) were determined. The amount of lime required for raising the pH of the soil to a level suitable for growth of groundnut was determined from this incubation study.

2.7. Treatments and Experimental Design

The treatments consisted of three rates of phosphorus fertilizer (0, 46 and 92 kg $P_2O_5 \cdot ha^{-1}$), three rates of lime (0, 6, and 11 ton lime$\cdot ha^{-1}$), and Three groundnut varieties (local cultivar, Werer-961, and Werer-963). With the soil depth of 20 cm and bulk density of 1.34 $g \cdot cm^{-3}$, the corresponding rates of phosphorus applied per pot (7 kg$\cdot$soil^{-1}) amounted to 0, 107, and 215 mg P_2O_5 kg$\cdot$soil^{-1} and those of lime amounted to 0, 14, and 26 g lime (7 kg$\cdot$soil^{-1}). The experiment laid-out as a randomized complete design (RCD) in a factorial arrangement and replicated five times. Thus, there were 3 × 3 × 3 = 27 treatment combinations constituting of 135 pots. The treatments were assigned to each pot randomly.

2.8. Soil Analysis

The soil samples were analyzed before and after harvesting to determine selected soil physical and chemical properties. The textural class was determined based on the soil textural triangle using the International Soil Science Society (ISSS) system. Soil pH (1:2.5 soils to water ratio) was determined using a glass electrode pH meter as described by [27]. CEC of the soil was determined from NH_4OAc saturated samples, which was determined through distillation using the micro Kjeldahl procedure. Total nitrogen was analyzed using the macro-Kjeldahl digestion method, followed by the ammonium distillation and titration method. Available P in the soil samples was determined following the procedure of Bray-II method. Organic carbon was determined following the wet digestion method. Exchangeable K was extracted by ammonium acetate (1 M NH_4OAc), extraction method at pH 7.0 and determined by flame photometry. Black density of the soil was measured by soil mass to soil volume. It is a measure of the density of a porous material that takes into describes the density of the solid material and the amount of porosity. Aluminum was determined by titration with NaOH, and Ca and Mg by titrating with Ethylene diammine tetra acetic acid.

2.9. Experimental Procedures and Treating Soil with Phosphorus and Lime

2.9.1. Applying the Fertilizer and Lime

The fertilizer and lime were applied to the batches of soil at each rate, after which the soil should have been filled into the pots at the approximate bulk density of the soil in the study area.

2.9.2. Sowing and Raising the Crop Plants

Plants were raised in open-air condition under a polyethylene sheet that had an area of (10 m × 6 m). Seeds of the three groundnut varieties sown in the pots each of which had a capacity of containing 7.0 kg soil and seedlings were later thinned to two plants per pot when the first trifoliate leaves unfolded. Pots were watered periodically to the approximate field capacity to facilitate normal plant growth. All other recommended agronomic management practices were applied to all plants grown in the pots. The first weeding was done two weeks after emergence of the seedlings, and then weeding was performed as required until the varieties started to set pegs and pods.

2.10. Data Collection and Measurement

The actual number of days from emergence to the stage when 90% of the plants in the pot produced flowers was determined by counting. The number of days from the date of sowing to the time when about 90% of the plants in the pot had dark-colored pods in their inner wall was considered the maturity time. The height (cm) of the plant from the base to the apex was measured using a ruler. The number of primary branches produced by the plants was determined by counting at physiological maturity from five replications. Total dry biomasses (kg) of the whole above and belowground of the economic part (including shoots pods and root) were recorded before physiological maturity or senescence (at full pod formation). The total nodule number per plant was determined by counting randomly from five replications after carefully uprooting the plants before flowering. Roots were carefully washed with clean water and the nodules counted. The number of pegs per plant was determined by counting randomly from five replications after flowering before pod setting. The number of pods per plant was determined by counting randomly from five replications at full pod formation. The weight of dry pods (kg) was determined after plucking the pods. The number of seed per pod was counted from five replication at crop maturity. For determining the hundred seed weight (g), 100 dried seeds were shelled from dried pod, and the seeds weighed. Shelling percentage was determined as the weight of groundnut seed divided by the weight of the dry pods. Harvest index (%) was calculated as the ratio of seed yield to the above ground dry weight per pot. This was determined by carefully uprooting the entire plants at senescence stage. Harvest index was determined by using the following formula:

$$\text{Harvest index}\left(\text{HI}\right)=\frac{\text{Economical yield}\left(\text{kg}\right)}{\text{Biological yield}\left(\text{kg}\right)}\times 100 \quad (1)$$

Phosphorus efficiency of groundnut was determined from the pot following grain efficiency index. For this purpose, grain efficiency index (GYEI) was used to classify groundnut cultivars into efficient, moderately efficient, and inefficient [28].

2.11. Grain Yield Efficiency Index of the Groundnut Varieties

Phosphorus grain yield efficiency index GYEI was calculated based on the formula described by [29] as follows:

$$\text{GYEI}=\frac{\left(\text{Yield a genotype at low nutrient level}\right)\times\left(\text{Yield of that genotype at high nutrient level}\right)}{\left(\text{Experimental mean yield of all genotype at low nutrient level}\right)\times\left(\text{Experimental mean yield of all genotype at high nutrient level}\right)} \quad (2)$$

2.12. Data Analysis

Data were subjected to analysis of variance (ANOVA) according to the Generalized Linear Model (GLM) of SAS [30] version 9.4 following the procedure of Fisher's test. Significant means were separated using LSD test at 5% level of significance.

3. Results

3.1. Soil Physical and Chemical Properties

From the soil analysis result, before sowing it was apparent that the soil textural class was sandy clay loam with constituents of sand (35%), clay (15%) and silt (50%) which is ideal for groundnut as the crop is grown mostly on light-textured soils ranging from coarse and fine sands to sandy clay loams [31]. The soil pH (H_2O) of 4.45 rated as very strong acidic, total nitrogen (0.23%) is as high, available phosphorus (6.75) as low, exchangeable calcium (1.65) as very low according to the classification of [32], the CEC (12.18) is low and Aluminum concentration of (4.9) as very high according to the rating of [33] (**Table 2**). Thus, moderate to low mineral content of the soil implied that there was necessity of applying phosphorus and lime to the experimental pot of the study area.

3.2. Days to Flowering

The number of days required by the plant to reach 50% flowering was significantly ($P < 0.05$) affected by the interaction of phosphorus, lime, and variety. For Werer-963, the plants that flowered earliest (27) were recorded at rate of lime

Table 2. Selected physical and chemical properties of soil samples taken from the experimental field at Nedjo, western Ethiopia, during the 2019 main cropping season.

Soil property	Before sowing		After harvesting		Reference
		Rating		Rating	
Clay (%)	15		15		
Silt (%)	50		50		
Sand (%)	35		35		
Textural class				Clay sandy loam	
pH (1:2.5 H_2O)	4.45	V. strongly acidic	6.5	Slightly acidic	Murphy [1968]
Organic carbon (%)	1.85	Medium	2.05	Medium	Tekalign Tadese *et al.* [1991]
Total N (%)	0.23	High	0.35	Very high	Tekalign Tadese *et al.* [1991]
Available P (mg P kg·soil^{-1}	6.75	Low	11.43	Medium	Cottenie [1980]
Exchangeable Ca [(cmol$_{(+)}$ kg·soil^{-1}]	1.65	Very low	5.3	Medium	FAO [2006]
Exchangeable Mg [(cmol$_{(+)}$ kg·soil^{-1}]	2.3	Medium	2.55	Medium	FAO [2006]
Exchangeable K [(cmol$_{(+)}$ kg·soil^{-1}]	0.95	High	1.32	Very High	FAO [2006]
Exchangeable Al [(cmol$_{(+)}$ kg·soil^{-1}]	4.9	Very high	2.25	Low	Gourley [1999]
CEC [(cmol$_{(+)}$ kg·soil^{-1}]	12.18	Low	22.2	High	FAO [2006]
Bulk density	1.34	Uncompacted	1.32	Uncompacted	Landon [1991]

(26 g·pot^{-1}) and phosphorus (215 mg P_2O_5·pot^{-1}). For Werer-961, the plants that flowered earliest (30) were recorded at rate of lime (26 g·pot^{-1}) and phosphorus application (107 mg P_2O_5·pot^{-1}). However, the delayed days to flowering (38) were recorded from Local variety at rate of 14 g·pot^{-1} with 0 g P_2O_5·pot^{-1}. This indicates that high lime and phosphorus application hastened flowering of the plants but delayed with nil lime and phosphorus applications (Table 3).

3.3. Days to 90% Physiological Maturity

Days to maturity was significantly ($P < 0.01$) influenced by interaction of cultivar, lime, and phosphorus application. For the local cultivar, the earliest maturing plants (149) were recorded in response to application of 14 g·pot^{-1} lime and 215 mg P_2O_5·pot^{-1}. For Werer-961 variety, the earliest maturity (148) was recorded in response to application of 26 g·pot^{-1} lime and 215 mg P_2O_5·pot^{-1}. Similarly, for Werer-963, the earliest maturity (144) of the plants was recorded in response to application of 14 g·pot^{-1} lime and 215 mg P_2O_5·pot^{-1}) (Table 3).

3.4. Plant Height (cm)

The height of the plants was significantly ($P < 0.01$) affected by the interaction of lime, phosphorus fertilizer, and variety. In response to interaction of applying 215 mg P_2O_5·pot^{-1} and 26 g·pot^{-1}, plants of Werer-963 variety were on average taller (55 cm) whereas the local cultivar with control lime and phosphorus

Table 3. Interaction effect of variety, phosphorus and lime on days to (50%) flowering, days to (90%) maturity, plant height, number of branches per plant, total dry biomass and number of nodules per plant at Nedjo ATVET College, western Ethiopia, during the 2019 main cropping season.

Groundnut variety	Lime (g·pot^{-1})	Phosphorus (mg P_2O_5·pot^{-1})	DFL	DM	PH (cm)	NPBP	TDB (kg)	NNPP
Local	0	0	35^{b}	155^{a}	36^{j}	2.1^{g}	0.23^{i}	13.0^{o}
		107	33^{c}	152^{b}	41^{g}	3.0^{f}	0.28^{h}	50.1^{k}
		215	32.5^{d}	150^{c}	40^{g}	4.7^{d}	0.27^{h}	55.3^{h}
	14	0	38^{a}	155^{a}	38^{h}	3.4^{f}	0.36^{f}	15.4^{n}
		107	34^{cc}	153^{b}	42^{f}	6.0^{c}	0.39^{e}	55.0^{h}
		215	36^{b}	149^{d}	43^{f}	5.2^{d}	0.48^{d}	60.1^{g}
	26	0	37^{a}	155^{a}	37^{i}	3.1^{f}	0.49^{d}	25.2^{m}
		107	30^{e}	151^{c}	49^{d}	6.3^{c}	0.62^{c}	55.3^{h}
		215	32.5^{d}	150^{c}	51^{c}	7.5^{c}	2.00^{b}	65.5^{f}
Werer-961	0	0	36^{b}	150^{c}	39^{h}	3.0^{f}	0.35^{g}	25.5^{m}
		107	35^{b}	152^{b}	44^{e}	5.1^{d}	2.13^{b}	52.1^{i}
		215	37^{a}	153^{b}	45^{e}	4.2^{d}	2.12^{b}	55.3^{h}
	14	0	35^{b}	151^{c}	38^{h}	3.0^{f}	0.39^{e}	55.2^{h}
		107	33^{c}	150^{c}	43^{f}	5.3^{d}	2.16^{b}	59.5^{g}
		215	31^{ef}	152^{b}	44^{e}	6.4^{c}	2.14^{b}	79.6^{e}
	26	0	31^{ef}	153^{b}	39^{g}	4.2^{d}	0.37^{f}	50.1^{j}
		107	30^{e}	149^{d}	51^{c}	7.1^{c}	2.26^{b}	65.2^{f}
		215	32^{d}	148^{d}	52^{b}	8.3^{b}	2.10^{b}	78.3^{e}
Werer-963	0	0	30^{e}	147^{e}	40^{g}	4.4^{d}	0.38^{e}	65.4^{f}
		107	29^{f}	148^{d}	44^{e}	5.5^{d}	2.16^{b}	78.6^{e}
		215	28^{g}	145^{f}	43^{f}	6.6^{c}	2.10^{b}	88.7^{c}
	14	0	33^{c}	149^{d}	39^{h}	3.9^{f}	0.37^{f}	79.0^{e}
		107	29^{f}	146^{e}	42^{f}	5.5^{d}	2.16^{b}	89.1^{c}
		215	28^{g}	144^{f}	49^{d}	6.3^{c}	2.13^{b}	98.3^{b}
	26	0	30^{e}	147^{e}	40^{g}	4.3^{d}	0.34^{g}	85.1^{d}
		107	29^{f}	145^{f}	53^{b}	8.2^{b}	2.20^{b}	97.4^{b}
		215	27^{h}	145^{f}	55^{a}	9.7^{a}	2.98^{a}	102.6^{a}
CV (%)			5.53	11.43	2.69	10.9	9.07	12.14
LSD			3.27	2.32	4.23	6.7	1.05	4.83

Means with the same letter are not significantly different; DFL = days to 50% flowering; DM = days to 50% maturity; PH = plant height; NPBP = number of primary branches per plant; TDB = total dry biomass; NNPP = number of nodules per plant; LSD = Least significant difference; CV = Coefficient of variation.

applications recorded the lowest plant height (36 cm) (Table 3). However, werer-961 variety produced medium (52 cm) plant height at application of applying 215 mg $P_2O_5 \cdot pot^{-1}$ and 26 $g \cdot pot^{-1}$ (Table 3).

3.5. Number of Primary Branches per Plant

The three factors, namely, lime, phosphorus fertilizer, and variety highly significantly ($P < 0.01$) influenced the number of primary branches per plant. The highest number of primary branches (9) per plant was produced by Werer-963 variety in response to the application of 14 g $lime \cdot pot^{-1}$ and 215 mg $P_2O_5 \cdot pot^{-1}$ (Table 3). However, Werer-961 variety produced on average (8) as many as number primary branches of as the number of primary branches produced by Werer-963 at these rates of lime and phosphorus fertilizer. The lowest number of branches (2) per plant was produced by the local variety and control treatments at application rate of no lime and phosphorus. This shows that Werer-963 is profoundly superior in producing stem branches as compared to the other varieties (Table 3).

3.6. Total Dry Biomass Yield ($kg \cdot pot^{-1}$)

The analysis of variance revealed that interaction of phosphorus; lime and variety were significantly ($P < 0.05$) affected the total dry biomass yield. The lowest total dry biomass yield (0.23 kg) was recorded for the local cultivar in response to application of 0 rate of lime and 0 rate of phosphorus. However, the highest total dry biomass yield (2.98 kg) was recorded for Werer-963 in response to application of 26 $g \cdot pot^{-1}$ lime and 215 mg $P_2O_5 \cdot pot^{-1}$. This shows that Werer-963 produced the highest the total dry biomass from the other varieties (Table 3).

3.7. Number of Nodules per Plant

The analysis of variance revealed that the interaction effects of phosphorus, lime, and variety were significantly ($P < 0.01$) influenced on the number of total nodule produced per plant. Accordingly, the highest number of nodules per plant (102) for Werer-963 was obtained in response to the application of 26 $g \cdot pot^{-1}$ lime and 215 mg $P_2O_5 \cdot pot^{-1}$. However, the highest nodules per plant for Werere-961 (78) and the local cultivar (65) were obtained in response to applying 26 g $lime \cdot pot^{-1}$ and 215 mg $P_2O_5 \cdot pot^{-1}$, respectively (Table 3).

3.8. Number of Pegs per Plant

The number of pegs produced per plant was significantly ($P < 0.01$) affected by the interaction of variety, lime, and phosphorus application. The highest number of pegs (40) per plant was produced by Werer-963 variety at application of 26 g $lime \cdot pot^{-1}$ and 215 mg $P_2O_5 \cdot pot^{-1}$. For Werer-961 variety, the highest number of pegs (18) per plant was recorded in response to the application of 26 g $lime \cdot pot^{-1}$ and 215 mg $P_2O_5 \cdot pot^{-1}$. However, the lowest number of pegs (3) per plant was obtained at nil rate of lime and phosphorus application for the local variety (Table 4).

3.9. Number of Seed per Pod

The number of seed produced per pod was significantly ($P < 0.05$) affected by the interaction of variety, lime, and phosphorus application. The highest number of seed (3) per pod was produced by Werer-963 in response to application of 14 g·pot^{-1} lime and 215 mg P_2O_5·pot^{-1} and as par with the application of 26 g·pot^{-1} lime and 215 mg P_2O_5·pot^{-1}. This was followed byWerer-961 (2.6) at 107 mg P_2O_5·pot^{-1} and 14 g·pot^{-1} lime application. The lowest number of seed per pod (1) was obtained from local cultivar at nil rates of phosphorus and lime (Table 4).

3.10. Number of Pods per Plant

The results showed that interaction of variety and phosphorus significantly ($P < 0.05$) influenced on the number of pods produced per plant. The highest number of pods (14) per plant was produced by Werer-963 at application of 215 mg P_2O_5·pot^{-1} (Table 5). This was followed by Werer-961 (13), which produced a relatively medium number of pods per plant in response to the application 215 mg P_2O_5·pot^{-1}. However, the lowest number of pods (4) per plant was obtained at nil rate of phosphorus application for the local variety (Table 5).

Table 4. Interaction effects of variety, phosphorus, and lime on the number of pegs per plant and number of seed per pod at Nedjo ATVET College, western Ethiopia during the 2019 main cropping season.

Lime (g·pot^{-1})	Phosphorus (mg P_2O_5·pot^{-1})	NPPP			NSPP		
		Variety					
		Local	Werer-961	Werer-963	Local	Werer-961	Werer-963
0	0	3.1^{o}	8.0^{k}	10.5^{j}	1.0^{i}	1.5^{e}	1.5^{e}
	107	6.2^{l}	12.3^{j}	25.1^{f}	1.5^{e}	1.5^{e}	2.0^{c}
	215	7.1^{l}	13.2^{i}	34.2^{d}	1.5^{e}	1.5^{e}	2.0^{c}
14	0	5.1^{m}	9.3^{k}	16.2^{h}	1.0^{i}	1.7^{d}	1.5^{e}
	107	8.2^{k}	13.1^{i}	30.3^{e}	1.5^{e}	2.3^{c}	2.6^{b}
	215	9.4^{k}	17.5^{h}	36.7^{c}	2.0^{c}	2.0^{c}	2.0^{b}
26	0	7.1^{l}	12.2^{j}	20.3^{g}	1.0^{i}	1.1^{f}	1.6^{e}
	107	9.2^{k}	14.3^{i}	38.5^{b}	2.6^{b}	2.0^{c}	2.7^{b}
	215	12.1^{j}	18.0^{g}	40.0^{a}	2.0^{c}	2.0^{c}	2.9^{a}
CV%			7.12			9.27	
LSD			5.43			1.21	

Where, means followed by the same letter within columns and rows are not significantly different at 5% probability level; NPPP = number of peg per plant; NSPP = number of seed per pod; LSD = Least significant difference; CV = Coefficient of variation.

Table 5. Interaction effects of variety and phosphorus on number of pods per plant at Nedjo ATVET College, western Ethiopia, during the 2019 main cropping season.

Phosphorus ($mg\ P_2O_5 \cdot pot^{-1}$)	Local	Variety	
		Werer-961	Werer-963
0	4.2^g	6.1^f	5.2^f
107	7.5^d	11.8^c	12.6^b
215	10.7^c	12.5^b	13.8^a
CV% = 6.37			
LSD = 3.06			

Where, means followed by the same letter with in columns and rows are not significantly different at 5% probability level; LSD = Least significant difference; CV = Coefficient of variation.

3.11. Total Dry Pod Yield ($kg \cdot pot^{-1}$)

The results of the analysis of variance showed that the interaction effects of variety, phosphorus and lime significantly ($P < 0.05$) influenced dry pod yield. The highest dry pod yield (2 $kg \cdot pot^{-1}$) was obtained from Werer-963 in response to applying phosphorus fertilizer at 107 mg $P_2O_5 \cdot pot^{-1}$ and 26 $g \cdot pot^{-1}$ lime (Table 6). This was followed by Werer-961 (1.5 $kg \cdot pot^{-1}$) which produced a relatively medium dry pod yield in response to the application of 215 mg $P_2O_5 \cdot pot^{-1}$ and 26 g $lime \cdot pot^{-1}$. However, the lowest number of dry pod yield (0.3 $kg \cdot pot^{-1}$) was obtained from the local variety at nil rates of phosphorus and lime (Table 6).

3.12. Shelling Percentage

The analysis of variance revealed that the interaction effects of phosphorus, lime and variety were highly significantly ($P < 0.01$) influenced on the shelling percent. Accordingly, the highest shelling percent (48.6%) was recorded fromWerer-963 in response to application of 26 g $lime \cdot pot^{-1}$ and 107 mg $P_2O_5 \cdot pot^{-1}$ (Table 6). However, the next maximum seed yields (46.0%) were obtained in response to application of 26 $g \cdot pot^{-1}$ lime and 215 mg $P_2O_5 \cdot pot^{-1}$ for variety Werer-961 (Table 6). On the other hand, the minimum shelling percent (34.0%) was obtained for the local variety in response to nil applications of both lime and phosphorus (Table 6).

3.13. Hundred Seed Weight (g)

The analysis of variance revealed that the interaction effects of phosphorus, lime, and variety were significantly ($P < 0.05$) affected hundred seed weight. The maximum hundred seed weight (38.9 g) was recorded from Werer-963 in response to application of 26 g $lime \cdot pot^{-1}$ and 107 mg $P_2O_5 \cdot pot^{-1}$ (Table 6). However, for the groundnut variety, Werere-961 the maximum hundred seed weight (36.2 g) obtained in response to the application of 26 g $lime \cdot pot^{-1}$ and 215 mg $P_2O_5 \cdot pot^{-1}$ (Table 6). On the other hand, the minimum hundred seed weight (30.1 g) obtained

Table 6. Interaction effects of variety, phosphorus, and lime on total dry pod yield, shelling percent and hundred seed weight at Nedjo ATVET College, western Ethiopia, during the 2019 main cropping season.

Groundnut varieties	Lime ($g \cdot pot^{-1}$)	Phosphorus ($mg\ P_2O_5 \cdot pot^{-1}$)	TDPY ($kg \cdot pot^{-1}$)	SH (%)	HSW ($g \cdot pot^{-1}$)
Local	0	0	0.3^{h}	34.0^{i}	30.1^{f}
		107	0.4^{h}	42.1^{d}	33.2^{d}
		215	0.6^{g}	43.1^{d}	34.1^{d}
	14	0	0.3^{h}	34.0^{i}	30.2^{f}
		107	0.8^{f}	41.0^{e}	34.3^{c}
		215	0.7^{g}	42.3^{d}	33.3^{c}
	26	0	0.4^{h}	35.2^{h}	30.1^{f}
		107	0.9^{f}	44.1^{c}	34.0^{c}
		215	1.0^{e}	45.0^{c}	35.1^{c}
Werer-961	0	0	0.7^{h}	35.0^{h}	31.1^{e}
		107	1.3^{d}	44.4^{c}	33.4^{d}
		215	1.1^{e}	42.6^{d}	34.0^{c}
	14	0	0.6^{i}	36.3^{g}	31.3^{e}
		107	1.2^{d}	44.2^{c}	33.1^{d}
		215	1.3^{d}	38.1^{f}	34.0^{c}
	26	0	0.6^{i}	37.2g	32.2^{e}
		107	1.2^{d}	45.3^{c}	35.0^{c}
		215	1.5^{c}	46.0^{b}	36.2^{b}
Werer-963	0	0	0.9^{f}	37.1^{g}	33.1^{d}
		107	1.3^{d}	42.0^{e}	34.2^{c}
		215	1.5^{c}	45.0^{c}	35.1^{c}
	14	0	0.8^{f}	35.0^{h}	33.2^{d}
		107	1.8^{b}	47.3^{b}	34.0^{c}
		215	1.5^{c}	46.5^{b}	35.3^{c}
	26	0	0.7^{h}	36.2^{g}	33.3^{d}
		107	2.0^{a}	48.6^{a}	39.9^{a}
		215	1.9^{b}	47.1^{b}	37.1^{b}
CV (%)			6.35	5.33	6.18
LSD			0.75	3.23	2.18

Means with the same letter are not significantly different; TDPY = total dry pod yield; SH% = shelling%; HSW = hundred seed weight; LSD = Least significant difference; CV = Coefficient of variation.

from local cultivar in response to nil applications of both lime and phosphorus.

3.14. Harvest Index (%)

The results of the analysis of variance revealed that the interaction effect of phosphorus, lime and variety were significantly ($P < 0.05$) influenced on harvest index. Raising the rate of lime and phosphorus applications increased the harvest index across the three varieties (Table 7). The highest harvest index (49%) was obtained for the Werer-963 variety in response to application of 14 g lime·pot^{-1} and 215 mg P_2O_5·pot^{-1}. This was followed by Werer-961 (43%), which had a relatively medium harvest index in response to application of 26 g·pot^{-1} lime and 215 mg P_2O_5·pot^{-1}. However, the lowest harvest index (18%) was obtained at nil rates of lime and phosphorus application for the local variety. Thus, harvest index of Werer-963 variety increased from 18% to 50% (Table 7).

3.15. Seed Yield (kg·pot^{-1})

The results of the analysis of variance revealed that the interaction effects of phosphorus, lime and variety were significantly ($P < 0.05$) influenced on seed yield. The maximum seed yield (1 kg·pot^{-1}) was recorded for Werer-963. However, the next maximum seed yields (0.65 kg·pot^{-1}) were obtained in response to the application of 26 g·pot^{-1} lime and 215 mg P_2O_5·pot^{-1} for variety Werer-961 (Table 7). On the other hand, the minimum seed yield (0.22 kg·pot^{-1}) was obtained for the local variety in response to nil applications of both lime and

Table 7. Interaction effects of variety, phosphorus, and lime on harvest index of plant and seed yield at Nedjo ATVET College, western Ethiopia, during the 2019 main cropping season.

Lime (g·pot^{-1})	Phosphorus (mg P_2O_5·pot^{-1})	Harvest index (%)			Seed yield (kg·pot^{-1})		
		Variety					
		Local	Werer-961	Werer-963	Local	Werer-961	Werer-963
0	0	18.1^{m}	20.5^{l}	24.5^{j}	0.22^{m}	0.24^{l}	0.26^{k}
	107	22.3^{k}	26.4^{i}	30.2^{g}	0.41^{h}	0.43^{g}	0.44^{f}
	215	29.2^{h}	30.8^{g}	32.2^{f}	0.43^{g}	0.46^{f}	0.56^{d}
14	0	20.4^{l}	23.9^{j}	36.1^{i}	0.31^{j}	0.32^{i}	0.35^{i}
	107	36.3^{i}	30.7^{g}	42.3^{e}	0.49^{e}	0.61^{c}	0.58^{d}
	215	39.5^{e}	40.5^{e}	49.5^{a}	0.41^{h}	0.57^{d}	0.62^{c}
26	0	20.3^{l}	24.3^{j}	36.6^{i}	0.40^{h}	0.45^{f}	0.48^{e}
	107	41.2^{f}	42.6^{f}	42.4^{f}	0.43^{g}	0.32^{i}	1.00^{a}
	215	42.1^{f}	43.7^{d}	45.1^{c}	0.50^{e}	0.65^{b}	0.65^{b}
CV%			5.14			18.74	
LSD			9.15			0.41	

Where, means followed by the same letter with in columns and rows are not significantly different at 5% probability level; LSD = Least significant difference; CV = Coefficient of variation.

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phosphorus (Table 7).

3.16. Phosphorus Yield Efficiency Index

The three groundnut varieties were classified as efficient or non-efficient by computing their respective seed yield efficiency indices as suggested by [29]. Accordingly, Werer-963 variety was found to have a seed yield phosphorus efficiency index of 1.71, which is in the range of efficient, the variety Werer-961 had a seed yield phosphorus efficiency index of 0.6, which is in the moderately efficient category, and the local cultivar has a seed yield phosphorus efficiency index of only 0.04, which is the inefficient category.

4. Discussion

The hastening effect of interaction of lime and phosphorus fertilizer on days to flowering and maturity might be due to improved physiological processes, which promote the growth of the crop leading to early flowering and maturity as compared to plants grown under no phosphorus and lime application. This is in line with the finding of [34] he reported liming which improves the favorable soil conditioning and acting as source of Ca and Mg essential for plant growth parameters of groundnut. [35] described that lime improve the availability of nutrients and their by increase groundnut yield. Increasing the rates of phosphorus and lime application significantly increased the height of groundnut plants and this is consistent with that of [36] also reported that increasing the rate of phosphorus from 30 to 60 kg $P_2O_5 \cdot ha^{-1}$ significantly increased the height of groundnut. Corroborating with the result, [37] reported that liming of acid soil increased the uptake of phosphorus and nitrogen and there by increased the height of groundnut. The significant increase in the number of primary branches produced per plant in response to increasing rates of lime and phosphorus may be attributed to the role of phosphorus plays in enhancing cell division and vigorous growth of plants as a consequence of increased soil pH. Thus, applying lime may have ameliorated soil acidity and enhanced availability of phosphorus, and other nutrients, thereby promoting growth of the groundnut plants. In agreement with this result, [38] reported that increasing the rate of phosphorus as a single or combined application increased the number of branches per plant. The highest number of primary branch on Werer-963, the moderate number of primary branch on Werer-961, and the inferiority number of primary branch on the local cultivar in terms of producing main branches may be attributed to the inherent genetic differences among the cultivars.

The increase in biomass yield in response to application of lime and phosphorus maybe attributed to the fact that, when the availability of certain essential nutrients such as phosphorus improved the allocation of assimilates to roots will decrease and the allocation to the vegetative and reproductive part of groundnut increased [39]. As a result, enhanced availability of major plant nutrients such as P, N, Ca, S, and Mg from the soil for uptake by the plants due to application of lime along with phosphorus might have contributed to increase in total dry biomass yield.

The number of total nodules increased as a result of phosphorus and lime application. In line with this result, [40] reported increased in nodulation of groundnut as a result of applying phosphorus along with lime, compared to application of lime alone [41]. The Peg production was higher for Werer-963 than the other two varieties. This shows Werer-963 variety can overcome soil acidity to grow higher number of pegs with the amendment of phosphorus and lime much better than the other two varieties. In line with the result, [42] reported that lime significantly increased number of pegs in groundnut.

The capacity of pod production was higher for Werer-963 than the other two varieties. Werer-963 variety was more phosphorus-efficient than the other two varieties at low phosphorus level. In line with the result, [43] reported that application of 50 kg $P_2O_5 \cdot ha^{-1}$ led to significant increases in pod numbers of groundnut compared to 0 kg $P_2O_5 \cdot ha^{-1}$. The results indicate that Werer-963 is a variety that can be grown in very acidic soils with superior productivity with the application of optimum rates of lime and medium rate of phosphorus compared to the Werer-961 and the local groundnut varieties. This signifies that Werer-963 variety is more tolerant to soil acidity than the other varieties whereas the local cultivar is the least tolerant to this soil condition and the list productive. However, Werere-961 seemed to be moderately tolerant to soil acidity.

The total dry pod yield of groundnut was increased as lime, and phosphorus application increased. This is as a result of liming enhances soil phosphorus availability to plants and increases the availability of nitrogen by facilitating the decomposition of organic matter. This is consistence with the results of [44] who reported that application of phosphorus influence yield of groundnut significantly and that of [45] who reported increased N uptake by groundnut plants under phosphorus fertilizer application which, may have resulted in improved vegetative growth and partitioning of photo assimilate to the pods. This postulation is consistent with that of [42] who reported that liming contributed to the supply of Ca^{2+} and significantly increased pod yield in groundnut.

The higher seed number per pod was obtained from Werer-963 (2.8) as a result of application of phosphorus and lime increased. This might be associated with better growth performance of groundnut when grown under sufficient phosphorus and lime condition. The results agree with the findings of [46] reported increased nutrient availability to groundnut greater utilization of assimilates in to the pods and ultimately increased the number of filled pods. The higher shelling percent as a result of combined application of phosphorus and lime is an indication of the contribution of Ca on pod filling and reduction of empty pods. Thus, in response to increasing lime and phosphorus fertilizer application, shelling percent increased by about 45%. Similar results were reported by [47] sole phosphorus application showed helpful response to shelling percentage. Thus, increase in pod yield will result to bigger seeds, thereby increasing the shelling percentage. Hundred seed weight is an important yield trait often associated positively with seed yield. This is in agreement with the results of [40] who reported a significant influence of phosphorus application on hundred seed weight of groundnut crop. In line with this result, [37] reported that liming in acid soils increased phosphorus and N uptake.

Harvest index also increased as a result of liming and phosphorus application. This result is similar with the findings of [48] who reported that the highest harvest index of groundnut was obtained from the application of 50 kg $P_2O_5 \cdot ha^{-1}$ with 0 $t \cdot ha^{-1}$ lime. Hence, the response in seed yield due to application of lime and phosphorus might be linked to possibly less sorption of applied phosphorus and its improved availability resulting in enhanced growth and development, thereby resulting in higher seed yield [49].

The results of the significant variations in P use efficiency observed among the groundnut cultivars are consistent with the findings [50] reported that Greater phosphorus acquisition enables crops to accumulate more phosphorus in their tissue than inefficient crops when grown under phosphorus deficient soils. The P efficient cultivar Werer-963 produced 80% (at 0 mg $P_2O_5 \cdot pot^{-1}$) and 60% (at 215 mg $P_2O_5 \cdot pot^{-1}$) higher seed yield than the inefficient local variety. This implies P efficient variety is more productive than P inefficient cultivars both under P deficient and P-sufficient conditions. The high phosphorus use efficiency of the efficient groundnut varieties might be linked to re-translocation of phosphorus from vegetative part and better utilization of the trans-located phosphorus for grain formation [51].

5. Conclusion

The soil of the study area is very strongly acidic and low in available phosphorus, and exchangeable calcium as well as very high in exchangeable aluminum. This means the soil poses a serious threat to the production of groundnut because of its aforementioned unfavorable chemical properties. Therefore, it was justified to test the hypothesis that application of lime and phosphorus improves the soil condition and productivity of the crop. Accordingly, Werer-963 produced the highest seed yield (1 $kg \cdot pot^{-1}$) at the 11 t $lime \cdot ha^{-1}$ and 46 kg $P_2O_5 \cdot ha^{-1}$. The variety Werer-961 produced the highest seed yield (0.65 $kg \cdot pot^{-1}$) at the rates of (11 $t \cdot ha^{-1}$) and phosphorus rate (92 kg $P_2O_5 \cdot ha^{-1}$). However, the local variety produced the lowest seed yield (0.5 $kg \cdot pot^{-1}$) at highest rates of both lime and phosphorus application. The results also demonstrate that groundnut varieties differed in phosphorus seed yield efficiency index (GYEI) in the order Werer-963 > Werer-961 > Local cultivar. This indicates that Werer-963 is more phosphorus-efficient than the other two cultivars. Therefore, cultivating Werer-963 (11 $t \cdot ha^{-1}$) and a moderate amount of phosphorus (46 $kg \cdot ha^{-1}$) may enhance the yield of the crop acidic soil condition. However, field research should be conducted to verify these results further.

Author Contribution Statement

Askalu Dessalegn: Performed the experiments; wrote the paper.

Nigussie Dechassa: Analyzed and interpreted the data.

Lemma Wogi: Conceived and designed the experiments.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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