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# Response of Coffee (*Coffea arabica* L.) Seedlings to Lime and Phosphorus Mineral Fertilizer at Jimma, Southwestern Ethiopia

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**Abstract**

Pot experiment was conducted at Jimma Agricultural Research Center, southwestern Ethiopia, to investigate the effects of lime and P mineral fertilizer on shoot (stem + leaf) and root (tap and lateral root) growth of Arabica coffee seedlings and establish optimum combination of these agricultural inputs that enhance the growth of the crop under nursery condition. Six lime rates [0, 2.31, 4.62, 6.93, 9.24 and 11.55 g/2.5 kg soil (pot)] and four P rates (0, 250, 500 and 750 mg P/ pot) were factorially combined and laid out in randomized complete block design with three replications. Results depicted that lime and P rates significantly ($P \leq 0.01$) affected plant height, stem diameter, leaf number and area, tap and lateral root length, stem, leaf and root dry matter and shoot to root ratio of coffee seedlings. The highest value of these parameters was recorded on pots treated with 2.31 g lime and 750 mg P/pot. Similarly, the interaction of lime and P rates significantly ($P \leq 0.01$) affected plant height, stem diameter, leaf number and area and stem, leaf and root dry matter of coffee seedlings. The highest and non-significant shoot and root growth was observed on pots treated with a combination of 0 g lime and 750 mg P/pot and 2.31 g lime and 250 mg P/pot. In conclusion, vigorous Arabica coffee seedlings for field planting could be produced by applying P at a rate of 750 mg P/pot or a combination of low lime (2.31 g lime/pot) and low P (250 mg P/pot) rate. However, the scenario might be quite different after planting coffee seedlings in the field. Thus, further investigation should be continued under field condition to evaluate growth and yield response of coffee trees and row and cup quality of green beans to varying levels of lime and P fertilizer and establish profitable levels of these agricultural inputs for sustainable production of the crop in the country.

**Keywords**: Acid soil, coffee seedlings, lime, phosphorus mineral fertilizer, shoot and root growth

## Introduction

Phosphorus is one of the essential nutrients in the nutrition of coffee trees. It promotes both shoot and root growth and their respective fresh and dry weight of coffee seedlings (Taye *et al*., 1999). Besides, it enhances the development of flower and fruit consequently yield of the crop will be increased (Njoroge, 1989, Coste, 1992, Paulos, 1994).

In contrast, the environmental conditions of the Ethiopian coffee growing tracts are part and parcel of tropical climate whereby highly weathered tropical soils, such as *Nitosols and Cambisols*, are dominant. They are acidic in nature, with pH values of 4.5 - 6.5 (Paulos, 1994). The clay minerals of these soils are dominated by oxides and hydroxides of Al and Fe, kaolinite and allophane and are prone to strong P fixation capacity (Mesfin, 2007). Consequently, the proportion of native and/or added P fertilizer that could be immediately available to a crop becomes inadequate and/or the residues of the fertilizer may be released very slowly (Somani, 1996; Mesfin, 2007; Brady and Weil, 2008). Hence, the soil requires addition of high doses of P fertilizers, which is above the actual requirement of the fertilized crop, to saturate its P sorption sites of the soil and leave sufficient P in the soil solution for plant uptake. However, with inevitable increase in the price of imported mineral fertilizers, application of heavy doses of phosphate mineral fertilizer for sustainable crop production is not within the reach of subsistence and small scale farmers. As a result, farmers either could not apply or apply sub-optimal level of inorganic fertilizer to their coffee orchard. Hence, the coffee trees suffered from problems associated under nutrition and remain less productive. This situation, therefore, warrants for search of soil fertility ameliorating practices, which retard the P-fixation capacity of the soil and increase availability of native and/or applied P to plants uptake in the soil.

Ameliorating acid soils by application of lime and/or P mineral fertilizer is among the leading option to restore the productivity of such chemically degraded soils (Somani, 1996; Mesfin, 2007; Brady and Weil, 2008; Fageria *et al*., 2011). The scant information from other coffee growing countries also indicates the possibilities of using lime for acid soil amendment to produce vigorous coffee seedlings (Rodrigues *et al.*, 2001). However, information on the beneficial effects of lime and inorganic P fertilizer on soil fertility for improved coffee production is virtually absent in Ethiopia. Hence, pot experiment was conducted at Jimma Agricultural Research Center, southwestern Ethiopia, with the objective to investigate the effects of lime and P mineral fertilizer on shoot and root growth of Arabica coffee seedlings and establish optimum combination of these agricultural inputs that enhance the growth of the crop under nursery condition.

## Materials and Methods

Pot experiment was conducted at Jima Agricultural Research Center, southwestern Ethiopia (latitude $7^0$ 46' N, longitude $36^0$ 0' E and altitude 1750 meters above sea level). The center receives an average annual rainfall of 1529 mm with the mean maximum and minimum temperatures of 25.0 and 11.2 $^0$C, respectively. The predominant soil at the site of the trial is *Eutric Nitosols* (Paulos, 1994) with an average pH of 5.1 (Table 1).

Table 1. Chemical properties of experimental soil

| **Properties** | **Values** |
|---|---|
| pH (1:2.5 soil:$H_2O$) | 5.1 |
| Exchangeable K | 0.56 $cmol_c$/kg |
| Exchangeable Ca | 5.44 $cmol_c$/kg |
| Exchangeable Mg | 2.47 $cmol_c$/kg |
| Exchangeable acidity | 1.80 $cmol_c$/kg |
| Cation exchange capacity | 23.20 $cmol_c$/kg |
| Total N | 0.105% |
| Organic carbon | 0.898% |
| Organic matter | 1.548% |
| Total P | 760 ppm |
| Available P | 2.4 ppm |

Six lime rates (0, 2.31, 4.62, 6.93, 9.24 and 11.55 g/pot) and four P mineral fertilizer rates (0, 250, 500 and 750 mg P/pot) were factorially combined and applied in 2.5 kg sieved top soil (pot). The experiment was laid out in randomized complete block design with three replications. Topsoil (0 - 25 cm) of *Nitosols* was air-dried, manually crushed and screened through a 2 mm sieve. The different lime rates as powdered lime having a calcium carbonate equivalent of 98% were weighted and thoroughly mixed with 2.5 kg of the sieved soil. Thereafter, the blend was depot in black polythene bags of 12 cm wide and 25 cm long, where each experimental unit consisted of 16 seedlings (pots).

Seeds of coffee berry disease resistant slection-7440 were sown at the rate of two seeds per pot and thinning to one seedling was made when the germinated seeds attain a butterfly growth stage. Phosphorus was applied as triple super phosphate (46% $P_2O_5$ or 20% P) once when the seedling attain a butterfly stage, while N was applied as urea (46% N) in three equal split, i.e., when the seedlings attained butterfly stage, two and four pairs of true leaves.

Four seedlings from the inner of each experimental unit were assessed for attributes of shoot [plant height (cm), stem diameter (cm) and leaf number and area ($cm^2$)] and root [tap and lateral root length (cm)] growth, when seven pairs of true leaves observed on good performing seedlings. Intact leaf area was determined using the procedure adapted by Yacob *et al*. (1995). To this end, the biomass of a seedling was partitioned in to shoot and root component. Then, roots were traced on a clean transparent glass placed above a square paper. The length of the root hairs per seedlings was calculated by counting the number of squares covered by individual root hair and multiplied by the length of a single square (0.05 cm). At the end, the shoot and root parts of the plant was oven dried at 70 $^0$C for 24 hours to a constant weight and dry matter measurement (g) was taken separately using sensitive balance. The dry weight of shoot and root was used to calculate shoot to root ratio the seedlings.

Bulk soil samples prior to the start of the experiment and soil samples after harvest of the seedling from each of the experimental plot was collected sparetly, air-dried on wooden tray and ground and sieved with a 2 mm sieve. The bulk soil sample was analyzed for pH, cation exchange capacity, exchangeable bases (K, Ca and Mg), exchangeable acidity (Al and H), organic carbon, organic matter, total N and total and available P. Besides, available P was determined for soil samples collected after harvest of the seedlings. Soil pH was measured using digital pH meter in 1:2.5 soil to water solution ratio (Page, 1982). Exchangeable acidity was determined following the method described by McLean (1965). Cation exchange capacity was determined according Champan (1965). Organic carbon was determined following the wet digestion method (Walkley and Black, 1934). Organic matter content was calculated by multiplying the percent organic carbon by 1.724 (Brady and Weil, 2008). Total N was determined by the Kjeldahil procedure (Jackson, 1956). Total and available P was determined with Bray II (Bray and Kurtz, 1945) extraction methods.

The shoot and root part of the plant that was harvested from each treatment and replication plot was oven dried at 70 $^0$C for 24 hours to and was ground to powder in stainless steel Wiley mill and sieved with 0.05 mm sieve. Phosphorus was determined by the ammonium vanadate molybdate method (Olsen *et al*., 1954). Finally, the collected data was subjected to analysis of variance for the design using SAS software (SAS version 9.1, 2008). Results were presented as means and was separated using Duncan's Multiple Range Test whenever the 'F' test was significant (Mandefero, 2005).

**Results and Discussion**

The addition of lime and P mineral fertilizer as a chemical amendment significantly ($P \leq 0.01$) affected plant height, stem diameter, leaf number and area, tap and lateral root length, stem, leaf and root dry matter and shot to root ratio of coffee seedlings (Table 2). The highest growth responses for the aforementioned parameters were recorded from seedlings treated with 2.31 g lime/pot, though statistically at par with seedlings not treated with lime. However, the application of lime at rates > 2.31 g/pot resulted in decrease of shoot and root growth parameters at a decreasing rate, culminating in the lowest values at the highest lime rate (11.55 g lime/pot) (Table 2).

Unlike lime rates shoot and root growth of coffee seedlings linearly increased with increasing P rates from 0 to 750 mg P/pot (Table 2). Accordingly, application of 750 mg P/pot increased plant height, stem diameter, leaf number and area, tap and lateral root length, stem, leaf and root dry matter and shot to root ratio by 60.9, 43.2, 45.8, 73.8, 8.64, 80.9, 84.8, 86.5, 74.3 and 43.9%, respectively, over unfertilized plot. This indicates the soil of the study area has very low available P. As a result, application of P fertilizers is mandatory on highly weathered and acidic coffee soils of Ethiopia. Furthermore, the increase in shoot and root growth with successive increment of P application observed in the present study apparently seems to be a good indicator of the existence of more room for increase of the parameters by applying P fertilizers at rates above 750 mg P/pot.

The better shoot and root growth response of coffee seedlings grown on pots treated with 0 and 2.31 g lime/pot could largely be attributed to the high available P (23.8 and 29.6 ppm, respectively), which was eleven times higher than the available P (2.4 ppm) of the study soil (Table 1 and 3). The decrease in growth of the seedlings at the highest lime rates might be attributed to decrease in solubility and availability of P, which is caused by the formation of insoluble Ca-P compounds in the soil (Naidu *et al*., 1990), the deficiencies of Fe, Mn, Zn and B and increased cations (K and Mg) retention capacity of soil colloids (Somani, 1996; Brady and Weil, 2008).

The least growth response of coffee seedlings in P unfertilized pot observed in this study is comply with the findings of Taye *et al*. (1999), who reported stunted shoot and root growth of Arabica coffee seedlings and thus reduced nutrient uptake under relatively nutrient deficient and poor physical media condition. Similarly, Chane (1991) reported that high growth response of coffee seedlings to fertilizer on nutrient poor soils and less to no response in nutrient rich soils.

Shoot and root growth of coffee seedlings significantly ($P \leq 0.01$) affected by the combined effects applied lime and P rates except for tap and lateral root length and shoot to root ratio where the effect was not significant. Accordingly, the highest but insignificant ($P > 0.05$) shoot and root growth were recorded for the interaction of 0 g lime and 750 mg P/pot and 2.31 g lime and 250, 500 and 750 mg P/pot in that order. In contrast, significantly the least different shoot and root growth were noticed on pots treated with a combination of no P fertilization and increased rate of lime (Figure 1). This indicates liming of inherently less fertile coffee soils without P fertilization adversely affect the growth performance of coffee seedlings.

**Conclusion and Recommendation**

The different lime rates significantly ($P \leq 0.01$) affected plant height, stem diameter, leaf number and area, tap and lateral root length, stem, leaf and root dry matter and shoot to root ratio of coffee seedlings. The highest values of these parameters were observed on pots treated with 2.31 g lime though statistically at par to seedlings no treated with lime.

Increased P rates significantly ($P \leq 0.01$) increased all the aforementioned growth parameters of coffee seedlings. Hence, the lowest and the highest values of these parameters were recorded from seedlings treated with 0 and 750 mg P/pot, respectively. The extent of increase in most of the values accrued due to the successive increment of P application apparently seem to be good indicator of the existence of more room for increase in growth of coffee seedlings by applying P at rates > 750 mg P/pot.

The interaction of lime and P also significantly ($P \leq 0.01$) affected the above mentioned parameters except tap and lateral root length and shoot to root ratio where the effects were non-significant. For all of the parameters the highest and non significant growth response was recorded by application of the 0 g lime and 750 mg P/pot and 2.31 g lime and 250 mg P/pot. Generally, growth of coffee seedlings was depressed with increasing rates of lime but no P fertilization.

In general, the findings of the present investigation indicate that coffee seedlings with better growth performance for field transplanting could be grown by applying P at a rate of 750 mg P/pot or by applying a combination of low lime (2.31 g/pot) and low P (250 mg P/pot) rate. However, further studies should be continued under field conditions to investigate growth and yield response of coffee trees and row and cup quality of green beans to different rates of lime and P fertilizer and establish economically profitable levels of these agricultural inputs for sustainable coffee production in the country by taking into account, *inter alias,* coffee cultivars, seasonal growth and fruiting pattern, management practices and climatic conditions.

Table 2. Shoot and root growth of Arabica coffee seedlings as affected by lime and P mineral fertilizer rates

| Lime and P rates | Shoot growth | | | | | | Root growth | | | Shoot to root ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | Plant height (cm) | Stem diameter (cm) | Stem dry matter (g) | Leaf number | Leaf area ($cm^2$) | Leaf dry matter (g) | Tap root length (cm) | Lateral root length (cm) | Root dry matter (g) | |
| **Lime rate (g/pot)** | | | | | | | | | | |
| 0 | 24.68a | 0.40a | 0.77ab | 11.71a | 20.07ab | 1.46ab | 25.32ab | 719.80a | 0.62ab | 3.35a |
| 2.31 | 25.11a | 0.41a | 0.88a | 11.85a | 21.01a | 1.53a | 26.96a | 729.92a | 0.66a | 3.41a |
| 4.62 | 21.92b | 0.38ab | 0.64bc | 10.73b | 17.96bc | 1.21b c | 24.68bc | 583.42b | 0.53b | 3.28ab |
| 6.93 | 20.64b | 0.36bc | 0.60c | 10.61b | 15.32cd | 0.94cd | 23.53cd | 539.14bc | 0.50bc | 3.00ab |
| 9.24 | 17.72c | 0.35c | 0.43d | 9.77b | 13.21d | 0.86d | 22.84d | 462.49cd | 0.41cd | 2.84bc |
| 11.55 | 15.08d | 0.30d | 0.31d | 8.71c | 9.98e | 0.58c | 22.69d | 403.43d | 0.33d | 2.45c |
| **Significance level** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| **SE (±)** | **0.72** | **0.01** | **0.05** | **0.26** | **0.74** | | **0.45** | **22.53** | **0.03** | **0.14** |
| **P rate (mg P/pot)** | | | | | | | | | | |
| 0 | 10.91d | 0.25d | 0.15c | 6.95c | 6.14d | 0.24d | 22.95b | 418.32c | 0.19d | 2.11c |
| 250 | 20.19c | 0.36c | 0.56b | 10.81b | 15.94c | 1.01c | 24.44ab | 589.68b | 0.49c | 2.89b |
| 500 | 24.46b | 0.40b | 0.76b | 11.74b | 19.51b | 1.40b | 24.46ab | 611.43ab | 0.61b | 3.46a |
| 750 | 27.89a | 0.44a | 0.99a | 12.82a | 23.46a | 1.78a | 25.12a | 672.72a | 0.74a | 3.76a |
| **Significance level** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| **SE (±)** | **0.59** | **0.01** | **0.04** | **0.21** | **0.61** | **0.06** | **0.36** | **18.40** | **0.03** | **0.11** |
| **CV (%)** | **12.04** | **6.30** | **26.23** | **8.60** | **15.80** | **25.57** | **6.25** | **13.62** | **21.92** | **15.52** |

** = Significant at 0.01 probability level. Mean within a column followed by the same letter(s) are not significantly different at 0.01 probability level.

Table 2. Available soil P as affected by the interaction of applied lime and P rates at harvest of coffee seedling

| Lime rate (g/pot) | Phosphorus rate (mg P/pot) | | | | **Mean** |
|---|---|---|---|---|---|
| | 0 | 250 | 500 | 750 | |
| 0 | 2.6 | 24.2 | 26.4 | 42.0 | **23.8** |
| 2.31 | 1.6 | 38.8 | 38.8 | 39.0 | **29.6** |
| 4.62 | 1.8 | 25.8 | 25.0 | 33.4 | **21.5** |
| 6.93 | 1.2 | 18.6 | 25.6 | 33.0 | **19.6** |
| 9.24 | 1.0 | 18.4 | 20.6 | 32.8 | **18.2** |
| 11.55 | 1.6 | 17.0 | 19.2 | 19.4 | **14.3** |
| **Mean** | **1.6** | **23.8** | **25.9** | **33.27** | **-** |

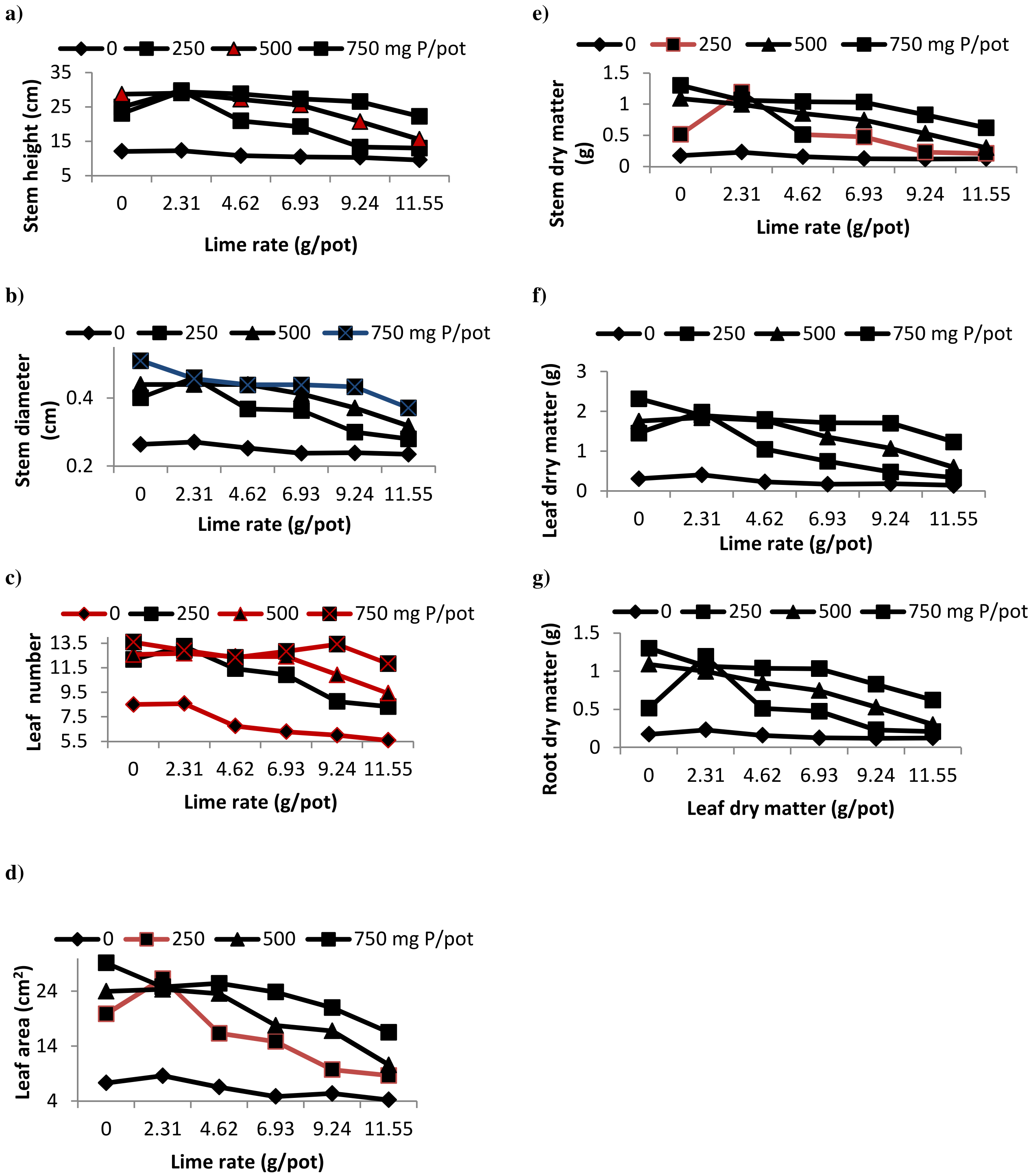


Figure 1. Stem height (a), stem diameter (b), leaf number (c), leaf area (d), stem dry matter (e), leaf dry matter (f) root dry matter (g) of coffee seedlings as affected by the interaction of lime and P mineral fertilizer rates.

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