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Dry Matter Production and Partitioning in Arabica Coffee Seedling as Affected by Lime and Phosphorus Mineral Fertilizer at Jimma, Southwestern Ethiopia

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Abstract

Nursery experiment was conducted at Jimma Agricultural Research Center, southwestern Ethiopia, to investigate dry matter production and its partitioning into above and below ground parts of Arabica coffee seedlings under different lime and P mineral fertilizer rates and establish optimum combination of these agricultural inputs that produce seedlings with better dry matter yield for field planting. 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 a randomized complete block design with three replications. Results showed that the main effect of lime and P mineral fertilizer significantly ($P < 0.01$) affect stem, leaf, root and total dry matter production and shoot to root ratio of coffee seedlings. The highest dry matter and shoot to root ratio was recorded from seedlings treated with 2.31 g lime and 750 mg P/pot. Similarly, the interaction of lime and P significantly ($P < 0.01$ or $P < 0.05$) affect the above mentioned agronomic parameters, except shoot to root ratio. The highest and insignificant dry matter recorded from seedlings treated with a combination of 0 g lime and 750 mg P/pot and 2.31 g lime and 250 mg P/pot. Thus, it is concluded that vigorous coffee seedlings with high dry matter content for field transplanting can be produced by applying P at a rate of 750 mg P/pot or by applying a combination of 2.31 g lime and 250 mg P/pot. But, further investigations should be continued under field conditions to evaluate growth and yield response of coffee trees and row and cup quality of green beans to varying levels of lime and P mineral fertilizer and establish economically profitable levels of these agricultural inputs for sustainable coffee production in the country by taking into account coffee cultivars, seasonal growth and fruiting pattern, management practices and climatic conditions.

Keywords: Acid soil, Arabica coffee, dry matter partitioning, dry matter production, lime, P mineral fertilizer

Introduction

Following nitrogen, phosphorus is the most commonly limiting plant nutrient in coffee growing areas of Ethiopia (Paulos, 1994). The soils are acidic in nature with pH values of 4.5 - 6.5 (Paulos, 1994) and dominated by oxides and hydroxides of Al and Fe, kaolinite and allophane and are prone to strong P fixation (Mesfin, 2007). As a result, the proportion of native and/or added P fertilizer that could be immediately available to crops becomes inadequate and residues of the fertilizer may be released very slowly. Apart from P deficiency, the low productivity of crops, in such soils, can mainly be attributed to the deficiency of Ca and Mg, low pH, toxicity of Al, Fe and Mn (Brady and Weil, 2008; Fageria *et al*., 2011; Marshner, 2012), low N supply (mainly NH_4^+ rather than NO_3^--N) (Rajan, 2000), Mo deficiency and toxic concentration of phenolic compounds (Hafner *et al*, 1992).

Acid soils with pH below 5.0 Al occupies the largest portion of the cation exchange sites of clay minerals by replacing divalent cations (Ca^{2+} and Mg^{2+}), which simultaneously it acts as a strong adsorber of phosphate ions (Kidd and Proctor, 2001; Brady and Weil, 2008; Fageria *et al*., 2011; Marshner, 2012). Hence, the soil requires addition of high doses of P fertilization above the actual requirement of the fertilized crop to saturate its P sorption sites 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 small scale and subsistence farmers. As a result, farmers either could not apply or apply sub-optimal level of inorganic fertilizers 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.

Addition of lime to acid soils has been advocated because it displaces P from precipitates of Al- and Fe-phosphate (Mesfin, 2007; Brady and Weil, 2008; Fageria *et al*., 2011) as well as making the exchange sites more active through the improvement in physico-chemical properties of the soils (Pandy, 1987; Somani, 1996; Brady and Weil, 2008). The scant information from other coffee growing countries also indicate that the possibility of using lime for acid soil amendments to produce vigorous coffee seedlings for field transplanting (Rodrigue *et al*., 2001). However, information on the effects of amending acidic soils of coffee growing tracts of Rthiopia using lime and P mineral fertilizer for improving soil fertility/productivity and coffee production is lacking. This study was, therefore, designed to evaluate the impacts of lime and P mineral fertilizer on dry matter production and partitioning into its above and below ground parts of Arabica coffee seedlings and establish optimum combination of lime and P mineral fertilizer rate that produce seedlings with better dry matter yield for field planting.

Materials and Methods

A factorial combination of six levels of lime [(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 laid out in randomized complete block design in three replications at Jimma Agricultural Research Center. The Center is found in the southwestern part of Ethiopia in Oromia National Regional State. It is located at coordinates of 7^0 46’ N latitude and 36^0 0’ E longitudes and at elevation of 1750 meters above sea level. It received an average annual rainfall of 1529 mm with the mean maximum and minimum temperatures of 25 and 11.2 ^{0}C, respectively. The predominant soil of the center is *Eutric Nitosols* with an average pH of 5.1 (Table 1).

Topsoil (0 - 25 cm) of *Nitosols* was collected from open field of the research center and air-dried and sieved with a 2 mm wire mesh. The different lime rates as powdered lime having a calcium carbonate equivalent of 97.5% were weighted and mixed thoroughly with 2.5 kg sieved soil on plastic sheet and filled in black polythene bags of 12 cm wide and 25 cm long where each experimental unit consisted of 16 seedlings (pots). Then after, seeds of coffee berry disease resistant selection- 7440 were sorted out for uniform size. Two seeds were sown per pot at a depth of 1.0 cm. Thinning to one seedling was made in each pot after the emerged seedlings attained a butter fly growth stage.

Phosphorus was applied as triple super phosphate (46% P_2O_5 or 20% P) once when the seedlings attain a butterfly growth stage, while N was applied uniformly as Urea (46% N) at a rate of 540 mg N to all pots in three equal split, when the seedlings attain butterfly stage and two and for pair of true laves. Except experimental variable all other routine management practices were uniformly adhered as per the recommendations (Tesfaye *et al*., 2005).

The center four seedlings per experimental unit were used for measurement of stem (stem + branch), leaf and root dry matter when seven pair of true leaves were observed on good performing seedlings. The seedlings sampled from each experimental unit brought into Coffee Agronomy/Physiology laboratory and were separated into shoot (stem + leaf) and root by cutting at its collar point with scissors. The shoots were then separated into stem and leaf. The polythene bag containing the root of the seedling was immersed in a bucket of water to dissolve the intact soil with the root of the seedling. To this end, all plant parts were put separately in labeled paper bag and 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 each part was used to determine the dry matter partition to stem, leaves and roots and total dry matter (stem + leaves + roots dry matter) and shoot to root ratio (stem + leaf dry matter ÷ root dry matter) of the seedlings.

After harvest of the seedlings, soil sample was collected from each of the experimental unit separately. The collected soil samples was air-dried on wooden tray and ground and sieved with a 2 mm sieve and analysed for available P with Bray II extraction methods (Bray and Kurtz, 1945). 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).

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

Results and Discussion

Stem dry matter production and partitioning

Addition of lime significantly ($P \leq 0.01$) affected stem dry matter production of coffee seedlings. The highest value of 0.88 g/pot recorded from pots treated with 2.31 g lime, but statistically at par with seedlings not treated with lime (0.77 g/pot) (Table 2). However, the least and significantly different stem dry matter (0.31 g/pot) was recorded from seedlings that received 11.55 g lime/pot. On the other hand, the highest (29.29%) and the lowest (25.27%) stem dry matter partitioning were recorded on pots treated with 6.93 and 9.24 g limet, respectively (Table 1).

Increased rates of P mineral fertilizer from 0 to 750 mg P/pot significantly ($P \leq 0.01$) increased stem dry matter from 0.15 to 0.99 g/pot. Similarly, dry matter partitioned to stem increased with increased rates of applied P. Thus, values ranging between 26.26 to 28.12% were recorded on pots not fertilized and fertilized with 750 mg P, respectively (Table 2).

Stem dry matter of coffee seedlings significantly ($P \leq 0.01$) differed due to the combined effects of applied lime and P rates. Consequently, the highest but statistically non-significant stem dry matter yield of 1.30, 1.19, 1.09, 1.07, 1.04, 1.04 and 1.00 g were recorded from seedlings treated with a combination of 0 g lime and 750 mg P/pot, 2.31 g lime and 250 mg P/pot, 0 g lime and 500 mg P/pot, 2.31, 4.62 and 6.93 g lime and 750 mg P/pot and 2.31 g lime and 500 mg P/pot, respectively (Figure 1a). In contrast, the least and insignificant dry matter were noted for the combination of 0 mg P/pot and increasing rates of lime. Except at P rates of 500 and 750 mg P/pot, where stem dry matter yield linearly decreased with increasing lime rate, curvilinear stem dry matter was observed to increased levels of lime (Figure 1a).

Leaf dry matter production and partitioning

Applied lime and P mineral fertilizer rates significantly ($P \leq 0.01$) affected leaf dry matter production. Accordingly, this parameter increased from 1.46 to 1.53 g on pots not treated with lime and treated with 2.31 g lime, respectively (Table 2). However, application of lime above 2.31 g/pot resulted in decrease of leaf dry matter production culminating the lowest value of 0.56 g at the highest lime rate (11.55 g/pot). On the other hand, the highest (51.28%) and lowest (46.34%) leaf dry matter accumulation was recorded from seedlings grown without lime and those treated with 6.93 g lime/pot, respectively (Table 2).

Leaf dry matter of coffee seedlings significantly ($P \leq 0.01$) increased with increasing P mineral fertilizer rates. As a result, the lowest (0.24 g) and the highest (1.78 g) leaf dry weight were recorded from seedlings grown with 0 and 750 mg P/pot, respectively (Table 2). Similarly, total dry matter partitioned to leaf increased with increased levels of P. The highest (50.83%) and lowest (41.57%) value of this parameter recorded on pots that received the highest and lowest P rates, respectively.

Interaction of applied lime and P rates significantly ($P \leq 0.01$) influenced leaf dry matter of coffee seedlings. The highest but non-significant leaf dry matter (2.32, 1.98 and 1.90 g/pot) was recorded on pots that received 0 g lime and 750 mg P and 2.31 g lime and 250 and 750 mg P, respectively (Figure 1b). However, the least and statistically non-significant leaf dry matter yield that ranged from 0.31 to 0.14 g/pot was recorded from pots received a combination of no P fertilization and no lime and lime applied at a rate of 11.55 g/pot. This indicates the adverse effects of liming inherently infertile coffee soil without P fertilization. Besides, the result revealed for each lime rate, application of P accentuated the effect of lime and the effects are greater with increased levels of P addition (Figure 1b). This could be associated to increase levels of available P (Table 3) for plant uptake, which render vigorous shoot growth.

In aggregate, the result presented in Table 2 and Figure 1b showed the highest amount (50%) of the total assimilates partitioned to the leaf part of coffee seedlings grown under the respective lime and P rates and their interaction effects. This is important, as leaf is the source of photosynthetic product to the other sink organs in coffee seedlings. This enables the plant to intercept more of the incoming photosynthetically active radiation during the growing season. This concurs with the reports of Rajan (2000) and Taye *et al.* (2001).

Root dry matter production and partitioning

Lime rates significantly ($P \leq 0.01$) affected root dry matter production. Accordingly, the highest root dry matter of 0.66 and 0.62 g were recorded from pots treated with 2.31 g and no lime, respectively. However, at lime level > 2.31 g/pot root dry matter linearly decreased with increasing lime rate (Table 2). Unlike the above ground parts, dry matter partition to roots was highest in pots treated with 11.55 g lime. As a result, the highest (26.79%) and the lowest (21.64%) values of the parameter were recorded on pots treated with 11.55 g lime and no lime, respectively.

The highest root dry matter production by coffee seedlings on pots received no lime and lime at a rate of 2.31 g/pot attributed to the improved levels of available P (Table 3), which enhanced root growth of coffee seedlings. On the other hand, the increase in dry matter partitioned to roots with increasing lime rate could be attributed to the impaired chemical characteristics of the soil, such as increase in pH and decrease in available P. This finding corroborates the findings of Taye *et al.* (2001), who reported enhanced partitioning of the total assimilate to roots of coffee seedlings under relatively nutrient deficient and poor physical media condition. This depicts that root is much stronger sink of the total assimilate under relatively nutrient stressed condition.

Applied P significantly ($P \leq 0.01$) influenced dry matter yield of root. Accordingly, the owest (0.19 g) and highest (0.74 g) root dry matter yield was recorded from seedlings treated with 0 and 750 mg P/pot, respectively. In contrast, this parameter was adversely influenced in the absence of P fertilization and hence the lowest (0.19 g) value was recorded (Table 2). However, total dry matter partitioned to the root decreased with increased level of P such that the lowest (21.02%) and the highest (24.44%) values were recorded on pots fertilized with 750 and 0 mg P/pot, respectively. This shows the roles of P in promoting dry matter of shoot and root of coffee seedlings (Taye *et al*., 2001; Wintgens, 2004).

Root dry matter production by coffee seedlings significantly ($P \leq 0.01$) influenced by the interaction of applied lime and P rates. At level of no P fertilization, roots dry matter of coffee seedlings was extremely depressed and no significant difference in root dry matter was observed with increasing lime rate (Figure 1c). Root dry matter of coffee seedlings grown in pots treated with 750 mg P/pot linearly decreased with increasing lime rate from 0 to 11.55 g/pot. However, applied P levels of 250 and 500 mg P/pot, including the control, revealed curvilinear root growth responses, where root dry matter increased with the increasing lime rates from 0 to 2.31 g/pot and above which it decreased with increasing lime rates (Figure 1c).

In general, a sharp decline in root dry matter with increasing lime rate above 2.31 g/pot was noticed for the lower P levels and the decrease was gradual for the higher P rates (Figure 1c). The gradual decrease in root dry matter at the highest P level with increasing lime rate could be attributed to the high amount of available P recovered in the soil solution from the addition of high levels of P (Table 2), which stimulate root hair formation and growth of lateral root for uptake of immobile P nutrient by the crop. In contrast, at lower P levels the rise in levels of Ca^{2+} ions in the soil which result from the increased levels of lime precipitates the small amount of added P and thus reduce P recovery in soil solution for plant uptake.

Total dry matter production

Applied lime significantly ($P \leq 0.01$) affected total dry mater yield of coffee seedlings. As a result, the seedlings attained maximum value of 3.06 g/pot with the application of 2.31 g lime/pot. However, application of lime at rates > 2.31 g/pot linearly decreased total dry matter production of the seedlings until it dropped to the lowest value of 1.22 g/pot at the highest level of applied lime (11.55 g/pot) (Table 2). Such reduction in total dry matter yield at high lime rate attributed to a reduction in the solubility and availability of P to crops which might be caused by the formation of insoluble Ca-P compounds in the soil (Naidu *et al*., 1990; Brady and Weil, 2008; Fageria *et al*., 2011; Marshner, 2012), to induced Fe, Mn, Zn and B deficiency (Hafner *et al*, 1992; Brady and Weil, 2008), to high level of Al in plant tissue (Friesen *et al*., 1980) and increased cation retention capacity of soil colloids and hence decreased availability of K and Mg (Kidd and Proctor, 2001). All these findings invariably illustrated that, depending on the type of crop species, lime rates which only raise the pH to levels that neutralize exchangeable Al or reduced it to lower levels increase crop growth and yield.

Phosphorus added to lime amended soil highly significantly affected total dry matter yield. Accordingly, total dry matter ranged between 0.58 to 3.49 g/pot were recorded for coffee seedlings fertilized with 0 and 750 mg P/pot, respectively (Table 2). The lowest total dry matter recorded from P unfertilized pots might be related to the low availability of P in the soil. This indicates the benefits of P fertilizer on such inherently infertile soil, a fact which has been recognized but which awaits quantification of the optimum level through research and further fine-tuning.

Interaction effects of applied lime and P rates were significantly ($P \leq 0.01$) affected total dry matter yield of coffee seedlings. Accordingly, the total dry matter yield of the seedlings on pots not treated with P was highly depressed and showed insignificant difference with increased lime rates (Figure 1d). However, at each lime rate, total dry matter yield of the seedlings increased with increased levels of P fertilization. Since the seedlings continued responding significantly in dry matter production up to the highest P level at each lime rate, it was not certain weather maximum growth of the crop was attained or not. In general, in pots supplied with 750 mg P, increased rates of applied lime was resulted inconsistent decrease of total dry matter production. However, with application of P at 250 and 500 mg P/pot, dry matter yield increased with increased lime rates from 0 to 2.31 g/pot and decreased with increased lime rates above 2.31 g/pot.

Shoot to root ratio

Shoot to root ratio of coffee seedlings significantly ($P \leq 0.01$) and non-significantly affected by the respective main and interaction effects of lime and P, respectively. Mean value of this parameter decreased from 3.41 to 2.45 when the rates of applied lime increased from 2.31 to 11.55 g/pot. On the other hand, increasing the level of applied P from 0 to 750 mg/pot increased shoot to root ratio of the seedlings from 2.11 to 3.76 (Table 2).

The decrease in shoot to root ratio of coffee seedlings with decrease in lime rate from 750 to 0 mg P/pot is mainly due to the deficiency of P in the pots. Under such P limiting growth conditions, the roots share more of the total assimilates than the shoot and subsequently leading to a typical decrease in shoot to root dry matter ratio (Ericsson and Ingestad, 1988). In harmony with these findings, Ericsson (1995) and Marshner (2012) pointed out the importance of availability of nutrients, water and assimilate for shoot growth. They further stated that when any of these factors was growth limiting, a large fraction of the water and nutrient taken up by the plant was retained in the roots, resulting in a decrease in the shoot to root ratio. Similarly, Marschner (2012) reported a negative and significant correlation between the decrease in shoot to root dry matter ratio in phosphate deficient plant and an increase in partitioning of the carbohydrates towards the root.

Conclusion and Recommendation

The different lime rates significantly ($P \leq 0.01$) affected stem, leaf, root and total dry matter production and shoot to root ratio of coffee seedlings. The highest and statically non-significant values of these parameters were observed on pots treated with 0 and 2.31 g lime.

Increased P rates highly significantly increased all dry matter yield and shoot to root ratio. Hence, the lowest and the highest values of the aforementioned 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 dry matter yield and shoot to root ratio 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 dry mater yield except shoot to root ratio where the effects were non-significant. Application of the highest P rate (750 mg P/pot) but without lime was resulted high shoot and root dry matter followed by low lime (2.31 g/pot) and low P (250 mg P/pot) rate combination. Dry matter yield of coffee seedlings was depressed with increasing rates of lime but no P fertilization.

In conclusion, coffee seedlings with high dry matter content for field transplanting could be grown by applying P at a rate of 750 mg P/pot or by applying low lime (2.31 g/pot) and low P (250 mg P/pot) rate combination. However, further studies should be continued under field conditions to investigate growth and yield response of coffee trees and row and liquor quality of green beans to different lime and P fertilizer rates and establish profitable levels of these agricultural inputs for sustainable coffee production in the country by taking into account coffee cultivars, seasonal growth and fruiting pattern, management practices and climatic conditions.

Table 2. Dry matter production (g/pot) and partitioning (%) and shoot to root ratio of coffee seedlings as affected by lime and P rates

Lime and P rate	**Stem dry matter**		**Leaf dry matter**		**Root dry matter**		Total dry matter production	Shot to root ratio
	Prodn.[†]	Partn.[‡]	Prodn.	Partn.	Prodn.	Partn.		
Lime rate (g/pot)								
0	0.77^{ab}	27.08	1.46^{ab}	51.28	0.62^{ab}	21.64	2.84^{a}	3.35^{ab}
2.31	0.88^{a}	28.27	1.53^{a}	50.03	0.66^{a}	21.70	3.06^{a}	3.41^{a}
4.62	0.64^{bc}	26.81	1.21^{bc}	50.94	0.53^{b}	22.13	2.38^{b}	3.28^{ab}
6.93	0.60^{c}	29.29	0.94^{cd}	46.34	0.50^{bc}	23.83	2.04^{c}	3.00^{ab}
9.24	0.43^{d}	25.27	0.86^{d}	50.71	0.41^{cd}	24.04	1.69^{c}	2.84^{bc}
11.55	0.31^{d}	25.80	0.58^{e}	47.41	0.33^{d}	26.79	1.22^{d}	2.45^{c}
Significance level	**		**		**		**	**
SE (±)	**0.05**		**0.07**		**0.03**		**0.13**	**0.14**
P rate (mg P /pot)								
0	0.15^{c}	26.26	0.24^{d}	41.57	0.19^{d}	24.44	0.58^{d}	2.11^{c}
250	0.56^{b}	27.55	1.01^{c}	49.85	0.49^{c}	24.33	2.06^{c}	2.89^{b}
500	0.76^{b}	27.26	1.40^{b}	50.56	0.61^{b}	22.15	2.76^{b}	3.46^{a}
750	0.99^{a}	28.12	1.78^{a}	50.83	0.74^{a}	21.02	3.49^{a}	3.76^{a}
Significance kevel	**		**		**		**	**
SE (±)	**0.04**		**0.06**		**0.03**		**0.10**	**0.11**
CV (%)	**26.23**		**25.57**		**21.92**		**19.51**	**15.52**

Prodn.[†] = Production, Partn.[‡] = Partitioning. ** = Significant at 0.01 probability level. Means within a column followed by the same superscript letter(s) are not significantly different at $P = 0.01$ probability level.

Table 3. 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**	**-**

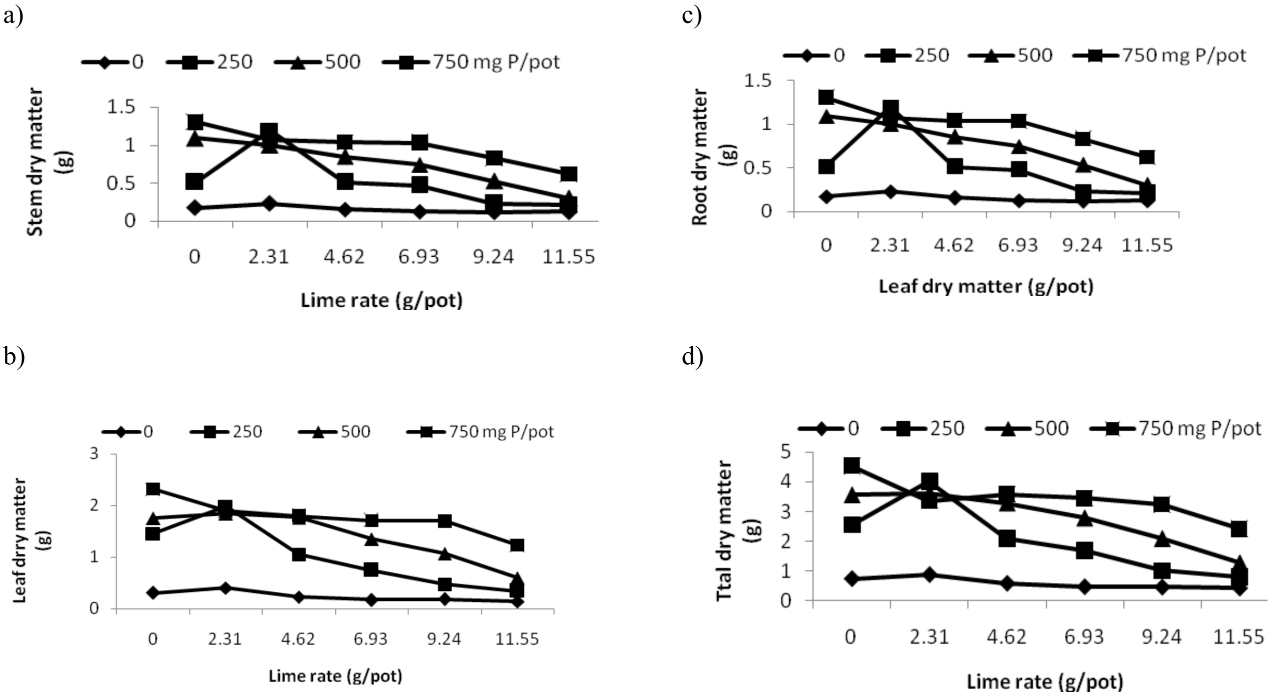

Figure 1. Interaction effects of lime and P rates on stem (a), leaf (b), root (c) and total (d) dry matter production by coffee seedlings.

References

Brady, N. C. and R. R. Weil. 2008. Nature and Properties of Soils (14th edn.). Prentice Hall, Upper Saddle River. 992p.

Bray, R. H. and L. T. Kurtz, 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Sci. Soc. Am. Proc.* 59: 36-45.

Erccson, T. and T. Ingested. 1988. Nutrition and growth of brich seedlings at varied relative phosphorus addition rates. *Journal of Plant Physiology*. 46: 609-613.

Erccson, T. 1995. Growth and shoot to root ratio of brich seedlings in relation to nutrient availability. *Plant and Soil*. 168-169: 205-214.

Fageria, N. K., V. C. Baligar and C. A. Jones, 2011. Growth and Nineral Nutrition of Field Crops (3rd edn.). New York. 550p.

Friesen, D. K., M. H. Miller and A. S. R. Juo. 1980. Liming and lime-pohosphorus-zinc interactions in two Nigerian Ultisols. II. Effects on maize root and shoot growth. *Journal of Soil Science Society of America*. 44: 1227-1232.

Hafner, H., B. J. Ndunguru, A. Batiano and H. Marschner. 1992. Effect of nitrogen, phosphorus and molybdenum application on growth and symbiotic N_2- fixation of groundnut in acid sand soil in Niger. Fertilizer Research. 31: 69-77.

IAR. 1996. Recommended production technologies for coffee and associated crops. IAR, Addis Ababa. 18p.

Kidd, P. S. and J. Proctor. 2001. Why plants grow poorly on very acid sols: Are eclogiest missing the obvious? *Journal of Experimental Botany*. 52(357): 791-799.

Mandefero Nigussie. 2005. Statestical procedure for designed experiments. Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia. 202p.

Marschner, P. 2012. Mineral Nutrition of Higher Plants (3rd edn.) Acadamic Press Elsevier Ltd., United States of America. 668p.

Mesfin Abebe. 2007. Nature and Management of Acid Soil in Ethiopia. Haramaya University, harmaya.

Naidu, R., R. W. Tillman, J. K. Syers and J. H. Kirkman. 1990. Lime-aluminium-phosphorus interactions and the growth of *Leucanea leucocephala.* I. Plant growth. *Plant and Soil*. 126: 1-8.

Pandy, N. 1987. Acid soil of Eastern India: Their chemistry and management. Journal *of Indian Society of Soil Science*. 35: 568-81

Paulos Dubale (ed.). 1994. Mineral Fertilizer of Coffee in Ethiopia. Institute of Agricultural Research, Addis Ababa, Ethiopia. 105pp.

Rajan, S. S. 2000. Plant Physiology. Anmol Publications PVT. LTD. New Delhi, India. 521pp.

Rodrigues, L. A., H. E. P. Martinez, J. C. L. Neves, R. F. Novais and S. M. Mendonia. 2001. Growth response of coffee tree shoot and root to sub-surface liming. *Plant and Soil*. 234: 207-214.

SAS Institute. 1990. SAS/STAT User's Guide 1990. SAS Institute Inc. Cary, NC.

Somani, L. L. 1996. Crop Production in Acid Soils. Agrotech Publishing Academy, Udaipur. 223p.

Taye Kufa, Paulos Dubale and Mesfin Abebe. 2001. Dry matter production and distribution in Arabica coffee as affected by Media components. The 10th Biannual Conference of Crop Science Society of Ethiopia, 19-21 June 2001, Addis Abeba, Ethiopia.

Tesfaye Shimber, Alemseged Yilma, Taye Kufa and Endale Taye. 2005. "Coffee seedlings management and production technology." Amharic version. EARO, Addis Ababa, Ethiopia.

Wintgens, J. N. (ed.). 2004. Coffee: Growing, Processing, Sustainable Production. WILEY-VCH Verlag GmbH and Co. KgaA. Weinheim. 976pp.