International Journal of Advanced Research in Biological Sciences
ISSN: 2348-8069
www.ijarbs.com
(A Peer Reviewed, Referred, Indexed and Open Access Journal)
DOI: 10.22192/ijarbs Coden: IJARQG (USA) Volume 12, Issue 4-2025

Research Article

DOI: http://dx.doi.org/10.22192/ijarbs.2025.12.04.005

Biomass Production and Partitioning of Coffee (*Arabica Coffea L.)* Seedlings as Influenced by Lime and Coffee Husk Compost Amendments on Acidic Soil of Haru, Western Ethiopia

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Abstract

Nursery experiment was conducted at Haru Agricultural Research Sub center of Jimma Agricultural Research Center, Western Ethiopia, to investigate biomass production and partitioning of Arabica coffee seedlings under different lime and coffee husk compost rates and establish optimum combination of these agricultural inputs that produce seedlings with better biomass production for field planting.The experiment was laid out in a factorial experiment arranged in randomized complete block design with three replications. The treatments included four levels of lime (0, 1.6, 3.2 and 4.8 t ha^{-1})and coffee husk compost (0, 5, 10 and 15 t ha^{-1}).Biomass production and partitioning data of coffee seedlings were collected and subjected to analysis of variance using SAS package and treatment means were compared at 0.05 probability using least significance difference.The results revealed that lime and coffee husk compost rates significantly ($P< 0.01$) affected biomass production and partitioning of coffee seedlings. The highest biomass production of coffee seedling were obtained from the application of 15 t ha^{-1}coffee husk compost and combined use of lime and coffee husk compost at the modest levels of 3.2 t ha^{-1}lime and 10 t ha^{-1}coffee husk compost with a nonsignificant variation. From the study, it can be concluded that application of 15 t ha^{-1}coffee husk compost or combining 10 t $ha^{-1}$of coffee husk compost and 3.2 t $ha^{-1}$of agricultural lime could be a promising alternative amendment for acid soil management and production of vigorous coffee seedlings with high biomass production in Haru areas. But, further investigations should be continued under field conditions across locations and seasons to evaluate the effects of liming and coffee husk composts in ameliorating soil acidity, and improving growth, yield, nutrient uptake and quality of coffee varieties and establish their profitable levels for sustainable soil fertility management and production of Wollega coffee in western Ethiopia.

Keywords: Biomass Production, Coffee husk compost, Coffee Seedling, Lime

1. Introduction

Coffee (*Coffea arabica L.*), originated in Ethiopia, is the second major traded commodity following to oil (Zelalem, 2013) and thus plays a vital role in the balancing of trade between developed and developing countries. Coffee is an important foreign exchange commodity, contributing in various degrees to the national income of the producing countries (Patricia, 2011). Coffee guarantees a solid basis for promotion of economic development of the producing countries. About 33 million people in 25 African countries derive their livelihoods by growing coffee on their subsistence farms and particularly, in Ethiopia 15 million people directly or indirectly deriving their livelihoods from coffee system (Gray *et al.,* 2013). Ethiopia is the largest producer of coffee in Sub-Saharan Africa and is the fifth largest coffee producer in the world next to Brazil, Vietnam, Colombia and Indonesia, contributing about 7-10% of total world coffee production (Gray *et al.,* 2013).

Despite the existence of enormous genetic diversity and importance of the crop in the national economy of the country, its production potential hardly exceeds 0.67 ton ha^{-1} (CSA, 2016). Such a low productivity of the crop mainly stems from drought, inadequate or excessive light or shade, low soil fertility and undulating topography and associated factors, such as soil erosion and soil acidity (IAR, 1996; Yacob *et al.,* 1996; Solomon *et al.,* 2008; Anteneh *et al.,* 2015; Melke and Ittana, 2015). In addition coffee cultivation mainly lies on the production of coffee seedlings with desirable characteristics under the recommended nursery management operations. Because any improper handling made at the early stage would remain to cause poor field performances and life span of coffee trees in the field (Anteneh *et al.,* 2015). In this regard, reports (IAR, 1996; Yacob *et al*., 1996) indicated the use of appropriate potting media from forest soil to produce vigorous and healthy coffee seedlings. However, there is diminished accessibility to the sources, and the accelerated deforestation practices would also call for alternative nursery media preparations from available organic sources with due consideration of both physical and chemical conditions given the well-established cultural practices of using organic material under traditional crop production in Ethiopia (Taye *et al.,*2001; Anteneh*et al.,* 2015).

Using compost and animal manures on crops almost always has the desirable effect since they contain substantial amounts of major and trace elements. Furthermore, they have a positive effect on the chemical and physical properties of the soil. Thus, they can be of tremendous benefit in heavily weathered coffee soils because they can improve the soil structure and its water holding capacity (Ano and Ubochi, 2007; Solomon *et al.,*2008). The need for renewable, locally available and cheaper options for supplying nutrient to crops is increasingly becoming important because of the need for sustainable agriculture (Ahmad *et al.,* 2006). With growing demands for sustainably produced agricultural produce for environmental, social and food safety reasons, the use and recycling of organic matter is becoming inevitable, particularly for the export market, which depended on commodities such as coffee (Chemura, 2014).

There is thus the need to recognize other potential organic amendment sources such as the by-products from wet and dry coffee processing. The dry method is commonly practiced and easily available at coffee producing areas in West Wollega. These coffee by-products are utilized in other coffee producing countries as soil amendments (Kasongo *et al.,* 2011; Dzung *et al.,* 2013; Kasongo *et al.,* 2013; Nduka *et al.,* 2015). While in Ethiopia enormous quantities are either dumped into streams or burnt in big piles, with contributions to environmental hazards (Solomon, 2006; Gezahegne *et al.,* 2011; Henok and Tenaw, 2014).Therefore, the objective of this study were: To investigate biomass production and partitioning of Arabica coffee seedlings under different lime and coffee husk compost rates and establish optimum combination of these agricultural inputs that produce seedlings with better growth and biomass production for field planting.

2. Materials and Methods

2.1 Description of the study area

The study was conducted at the Haru Agricultural Research Sub-Center (HARSC) in West Wollega zone, Oromia National Regional State, Western Ethiopia. Haru Agricultural Research Sub-center of the Jimma Agricultural Research Center was established in 1998 primarily to address the potentials and constraints in west Wollega specialty coffee growing areas. The center represents the sub-humid tepid to cool mid highlands coffee agro-ecological zone in West Ethiopia. It is found at 28 km from Gimbi town of West Wollega zone and 466 km from Addis Ababa in western Ethiopia. The area is geographically located between the latitude of 8°54' 30" North and longitude of 35°52' 0" East at an elevation of 1750 m.a.s.l. The area is characterized by uni-modal rainfall pattern with an average annual rainfall of 1700 mm. The rainy season starts in March or May and extends up to October. The mean maximum and minimum air temperature is 27.8^{o}Cand 12.4 ^{o}C, respectively. The soil type of the center is Acrisols and sandy clay loam (Zebene and Wondwosen, 2008).

2.2 Experimental materials and procedures

Fresh coffee husk was collected from the dry coffee processing site in Jitu town, Haru District. The compost was prepared by using 70% coffee husk, 20% animal manure and 10% top soil by volume following the procedure adopted by Solomon (2006). Top soil at a depth of 0-20cm was collected from open field which is less fertile and acidic soil to be amended with coffee husk compost and lime. Moreover, the different lime rates as powdered lime having a calcium carbonate equivalent of 98% was used and amount of lime applied at each was calculated on the basis of exchangeable acidity concentration of the soil and crop factor tolerant to soil acidity (Kamprath, 1984). Menesibu coffee variety was used as test crop. The variety was released in the year 2010 for Wollega specialty coffee producing areas (EIAR, 2015). Coffee seeds were hand harvested from the already established seed orchards at Haru center and prepared as per the standard procedures.

2.3 Experimental treatments and design

The treatments consisted of four coffee husk compost application rates (0, 5, 10 and 15 t ha^{-1}) and four lime rates (0, 1.6, 3.2, and 4.8 t ha^{-1}) which is (0, 6.25, 12.5 and 18.75g) and (0, 2, 4, 6g) coffee husk compost and lime respectively in 2.5 kg of acidic soil. The treatments were conducted using polythene bags of 12 x 22 cm size. The polythene bags were prepared and firmly filled with the treatment rates which were added and thoroughly mixed with the soil. A 4 x 4 factorial experiment arranged in a randomized complete block design with three replications was used for the study. The so prepared pots were arranged and two coffee seeds were directly sown in polythene bags (potted) at a depth of 1.00 cm. Thinning to one seedling was made in each pot after the emerged seedlings attained a butterfly growth stage and were uniformly managed until they attain desirable stage and end of the study. All other routines pre-and post-nursery management practices, including mulching, watering, shading, weeding and other activities were carried out as per the recommendation (IAR, 1996).

2.4 Data collection

The center four coffee seedlings per experimental unit were used for measurement of biomass production of the seedlings. Coffee seedling growth parameters were recorded using appropriate measurement materials. The destructive data were also recorded to evaluate growth of each plant part. Shoot and root parts of the seedlings were separated by cutting plant at the collar point using scissors. Then, shoot parts were separated in to leaves and stems, and their fresh weights were measured by sensitive balance and expressed in gram per plant. All plant parts were separately placed in labeled paper bag and dried in oven dry at 70^{0}C until the constant weight and dry matter yield was measured for each sample using sensitive balance. The dry weight of each plant part, was used to determine the dry matter partitioned to stem, leaves and roots and total dry matter yield (stem + leaves + roots dry matter) of the seedlings (Yacob*et al.,* 1995). The dry-biomass partitioning to each plant body (leaf, stem, and root) were determined using equation1:

$$PP\ (\%) = \frac{PPDW}{TDY} * 100 \qquad \text{equation (1)}$$

Where, PP=percent of dry biomass partitioned to leaf, stem or root separately, PPDW=plant part dry weight (leaf, stem and root), TDY=total dry matter yield.

2.5 Statistical analysis

The collected soil and plant data were summarized and subjected to ANOVA (analysis of variance) using SAS software (version 9.3) (SAS, 2011). For significantly different treatments, the means were separated using Least Significance Difference (LSD) at p = 0.05.

3. Results and Discussion

3.1 Biomass Production of Coffee Seedlings

3.1.1 Leaf Dry Weight

Analysis of variance on coffee seedling leaf dry matter weight showed highly significant ($p \leq 0.01$) difference among the treatments. Accordingly application of lime without coffee husk compost produced a significant increase in leaf fresh and dry weight of coffee seedling with the magnitude of increment 25-108%, over the control with increasing lime rate (Table 1). The results indicate that applying lime to the soil might considerably improve the nutrient availability, particularly phosphorus, since it improve soil pH under which maximum availability of the nutrient may be obtained. Similarly, application of coffee husk compost without lime increased coffee seedling leaf dry matter weight by 108.3-266.7%, over the control with increasing rate (Table 1). The result was in line with Kasongo et al. (2013) who reported the application of coffee husk increased dry matter of rye grass on tropical acid soil. The highest leaf dry matter weight (0.44 g) was obtained from plots received the highest coffee husk compost rate without lime (15 t/ha) and followed by combined application of lime (3.2 t/ha) and coffee husk compost (10 t/ha) which gave 0.43 g leaf dry matter weight. While the lowest leaf dry weight (0.12 g) was obtained from untreated (control) plot (Table 1). This could be due to the favorable chemical status of the media including increased organic carbon (organic matter), total nitrogen, available phosphorus and exchangeable bases contributed to better coffee seedling growth.

3.1.2 Stem Dry Weight

Application of lime and coffee husk compost and their interaction gave highly significance difference ($p \leq 0.01$) on stem dry weight (Table 1). Accordingly, the highest stem dry weight (0.25 g) was obtained from plots received the highest coffee husk compost rate (15 t/ha) and followed by combined application of lime (3.2 t/ha) and coffee husk compost (10 t/ha) which gave 0.23 g stem dry matter weight. While the lowest stem dry weight (0.12 g) was obtained from untreated (control) plot (Table 1). The results indicate that applying lime and compost to the soil might considerably improve the nutrient availability, particularly phosphorus since it improves soil pH under which maximum availability of the nutrient may be obtained and as a result, coffee seedling growth parameters were improved.

3.1.3 Root Dry Weight

The interaction of lime and coffee husk compost rates significantly affected ($p \leq 0.01$) root dry matter. The highest root dry matter weight (0.23 g) was obtained from plots received the highest coffee husk compost rate (15 t/ha) and followed by combined application of lime (3.2 t/ha) and coffee husk compost (10 t/ha) which gave 0.23 g/pot root dry matter weight (Table 1). While the lowest root fresh and dry weight (0.57 and 0.09 g/pot) was obtained from untreated (control) plot (Table 1). The significant effect obtained by the application of lime and compost on coffee seedling shoot and root dry matter weight could be because of more favorable chemical conditions of the media such as reduced Aluminum toxicity and increased nutrient availability which ultimately enhanced coffee seedling growth. Similar findings were reported by Tayeet al. (2001), Anteneh (2015) and Ewnetu et al. (2019) at Jimma, Southwest Ethiopia. Although the combination of lime up to 3.2 t/ha and coffee husk compost 10t/ha significantly increased the coffee seedling growth, increasing lime and coffee husk compost rate in their combination above the mentioned rate (3.2 t/ha Lime and 10 t/ha coffee husk compost) retarded the coffee seedling growth.

3.1.4 Total Dry Weight

Analysis of variance showed significant differences due to the main effect of lime ($P<0.05$) and compost and interaction effects ($P<0.01$) on total dry matter yield. Results showed that application of lime without compost produced a significant increase in total dry matter yield. The magnitude of increment was 14.7 - 61.8% for total dry matter over the control with increasing rate (Table 1).The results indicate that applying lime to the soil might considerably improve the nutrient availability, particularly phosphorus, since it improve soil pH under which maximum availability of the nutrient may be obtained. Similarly, application of compost alone increased total dry matter yield by 61.8 - 170.6 % over the control with the highest yield from the highest rate (Table 1).

The highest total dry matter yield (0.92g/pot) was obtained from plots received 18.75 g pot^{-1} (15 t ha^{-1}) compost without lime and followed by combined application of 3.2 t ha^{-1} (4 g pot^{-1}) lime and 10 t ha^{-1} (12.5 g pot^{-1}) compost which gave 0.88 g/pot for total dry matter. While, the lowest total dry matter (0.34g pot^{-1})was obtained from untreated (control) plot (Figure 1).The increase in total dry matter could be because of decrease in soil acidity which attributed to improved root environment for nutrient availability as well as uptake by coffee seedlings as a result of lime and compost application. This could have been also the reason for poor performance in the control treatment. The result was in line with Anteneh (2015), who reported significant increase in total dry matter yield of coffee seedlings due to lime and P amendments on acidic soil.

Although the combination effect of lime up to 3.2 t ha^{-1}(4g pot^{-1}) and compost 10 t ha^{-1} (12.5g pot^{-1}) significantly increased the total dry matter yield, increasing lime and compost rate in their combination above the mentioned rate (3.2 t ha^{-1} lime and 10 t ha^{-1} compost) decreased the total dry matter yield. Also lime application on the highest compost rate (15 t ha^{-1}) did not increased the total dry matter. This shows that the potential of the used compost to ameliorate soil acidity without lime as mentioned in the literatures (Kasongo *et al.,* 2013; Nduka *et al.,* 2015). As well as the reduction in total dry matter yieldat increased rate of their combination 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 (Fageria and Baligar, 2008), to induced Fe, Mn, Zn and B deficiency (Fageria, 2009), to high level of Al in plant tissue (Fageria and Baliger,2008; Kochian *et al*.,2015) and increased cation retention capacity of soil colloids and hence decreased availability of K and Mg (Fageria and Baligar, 2003). 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.

Table 1. Mean value of biomass production of coffee seedling as affected by lime and coffee husk compost amended acidic soil

Treatment description	Leaf Dry Weight(g)	Stem Dry Weight(g)	Root Dry Weight(g)	Total Dry Weight(g)
Control	0.123^{i}	0.123^{j}	0.093^{i}	0.340^{k}
1.6 t ha^{-1} L	0.153^{hi}	0.136^{ij}	0.116^{h}	0.393^{j}
3.2 t ha^{-1}L	0.190^{h}	0.146^{hi}	0.140^{g}	0.456^{i}
4.8 t ha^{-1}L	0.253^{g}	0.150^{ghi}	0.153^{efg}	0.546^{h}
5 t ha^{-1}CHC	0.250^{g}	0.156^{fgh}	0.140^{g}	0.546^{h}
1.6 t ha^{-1}L+ 5 t ha^{-1}CHC	0.263^{g}	0.166^{defg}	0.146^{fg}	0.580^{gh}
3.2 t ha^{-1}L +5 t ha^{-1}CHC	0.290^{fg}	0.160^{efgh}	0.153^{efg}	0.603^{fg}
4.8 t ha^{-1}L+ 5 t ha^{-1}CHC	0.343^{cde}	0.180^{d}	0.173^{cd}	0.693^{de}
10 t ha^{-1}CHC	0.306^{ef}	0.173^{def}	0.146^{fg}	0.650^{ef}
1.6 t ha^{-1}L + 10 t ha^{-1}CHC	0.356^{cd}	0.203^{c}	0.183^{c}	0.753^{c}
3.2 t ha^{-1}L +10 t ha^{-1} CHC	0.433^{a}	0.230^{b}	0.226^{a}	0.880^{a}
4.8 t ha^{-1}L +10 t ha^{-1} CHC	0.366^{bc}	0.176^{de}	0.170^{cd}	0.730^{cd}
15 t ha^{-1} CHC	0.440^{a}	0.256^{a}	0.233^{a}	0.916^{a}
1.6 t ha^{-1}L +15 t ha^{-1} CHC	0.400^{ab}	0.210^{c}	0.200^{b}	0.813^{b}
3.2 t ha^{-1}L +15 t ha^{-1} CHC	0.290^{fg}	0.176^{de}	0.166^{de}	0.640^{f}
4.8 t ha^{-1}L +15 t ha^{-1} CHC	0.320^{def}	0.153^{ghi}	0.160^{def}	0.640^{f}
LSD (5%)	**0.043**	**0.017**	**0.014**	**0.052**
CV (%)	**8.65**	**5.94**	**5.16**	**4.93**

LSD= Least significance difference; L=Lime; CHC=Coffee husk compost; g= gram. Mean values within a column followed by the same letter(s) are not significantly different from each other at P≤0.05

3.2 Biomass Partitioning of Coffee Seedlings

Analysis of variance revealed that, biomass partitioning of coffee seedling was significantly (P<0.01) affected due to the interaction effect of lime and coffee husk compost (Table 2). Accordingly, the highest biomass partitioned to leaf (50.30%) was recorded for combined application of 3.2 t ha^{-1} (4 g pot^{-1}) lime and 10 t ha^{-1} (12.5 g pot^{-1}) coffee husk compost, while the lowest was obtained from control plot (Table 2). Conversely, the highest biomass to stem (36.27%) and root (27.44%) was recorded for control plot, while the lowest biomass to stem (23.93%) and root (24.06%) was recorded from combined application of 4.8 t ha^{-1} lime and 15 t ha^{-1} coffee husk compost and 15 t ha^{-1} coffee husk compost respectively.

In aggregate, the result presented in Table 2 showed the highest amount (50.30%) of the total assimilates partitioned to the leaf part of coffee seedlings grown under the respective lime and coffee husk compost rates and their interaction effects. This is important, as leaf is the source of photosynthetic product to the other sink organs in coffee seedlings. On the other hand, the increase in biomass partitioned to roots with control plot (without any amendment) could be attributed to the impaired chemical characteristics of the soil, such as decrease in available nutrients. This finding corroborates with 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.

Table 2. Mean value of biomass partitioning of coffee seedling as affected by lime and coffee husk compost amended acidic soil

Treatment description	Leaf Partition(%)	Stem Partition (%)	Root Partition(%)
Control	36.27^{f}	36.27^{a}	27.44^{a}
1.6 t ha^{-1} L	39.11^{ef}	34.45^{ab}	26.34^{abc}
3.2 t ha^{-1} L	41.58^{e}	32.11^{b}	26.29^{abc}
4.8 t ha^{-1} L	46.32^{bdc}	27.45^{cde}	26.22^{abc}
5 t ha^{-1} CHC	45.75^{dc}	28.60^{cd}	25.64^{bcd}
1.6 t ha^{-1} L+ 5 t ha^{-1} CHC	45.39^{d}	28.77^{c}	25.83^{bcd}
3.2 t ha^{-1} L +5 t ha^{-1} CHC	48.07^{abcd}	26.50^{cdef}	25.41^{cde}
4.8 t ha^{-1} L+ 5 t ha^{-1} CHC	49.46^{ab}	26.01^{def}	24.52^{de}
10 t ha^{-1} CHC	47.00^{abcd}	26.80^{cde}	26.19^{abc}
1.6 t ha^{-1} L + 10 t ha^{-1} CHC	47.25^{abcd}	27.05^{cde}	25.69^{bcd}
3.2 t ha^{-1} L +10 t ha^{-1} CHC	49.24^{abc}	26.13^{cdef}	24.62^{de}
4.8 t ha^{-1} L +10 t ha^{-1} CHC	50.30^{a}	24.08^{f}	25.61^{cd}
15 t ha^{-1} CHC	48.08^{abcd}	27.85^{cde}	24.06^{e}
1.6 t ha^{-1} L +15 t ha^{-1} CHC	49.06^{abc}	25.87^{ef}	25.07^{cde}
3.2 t ha^{-1} L +15 t ha^{-1} CHC	45.13^{d}	27.73^{cde}	27.13^{ab}
4.8 t ha^{-1} L +15 t ha^{-1} CHC	50.01^{a}	23.93^{f}	26.03^{abcd}
LSD (5%)	**3.5**	**2.69**	**1.51**
CV (%)	**4.55**	**5.75**	**3.53**

LSD= Least significance difference; L=Lime; CHC=Coffee husk compost; Mean values within a column followed by the same letter(s) are not significantly different from each other at P≤0.05

4. Summary and Conclusion

In the evaluation of the response of coffee (*Coffea arabica* L.) biomass production and partitioning following incorporation of coffee husk compost and agricultural lime amendments on acid soil, the study found that coffee seedling biomass production increased progressively with increase in coffee husk compost rates. Also vigorous coffee seedlings with high biomass production were obtained by combined application of coffee husk compost and lime at the rate of 10 t ha^{-1} and 3.2 t ha^{-1} respectively. However the biomass production of coffee seedlings at the highest rate of their combination (lime and coffee husk compost) were retarded.

In conclusion, this short-term study showed that a promising potential of coffee husk compost amendment alone or in combination with conventional lime to ameliorate soil acidity and improve biomass production for coffee seedling growth. However these findings need to be further confirmed by long term field experiments for different soil types and crops, which is critically important to further assess the potential of coffee husk compost amendment to be used as liming material for sustainable coffee production and for mitigation of the problem of soil acidity since it is easily available organic material in coffee producing areas.

Conflict of Interest

The author declare that there are no conflicts of interest regarding the publication of this manuscript

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Quick Response Code	Subject: Agricultural Science
DOI:10.22192/ijarbs.2025.12.04.005	

How to cite this article:
Bikila Takala Dibaba. (2025). Biomass Production and Partitioning of Coffee (*Arabica Coffea L.)* Seedlings as Influenced by Lime and Coffee Husk Compost Amendments on Acidic Soil of Haru, Western Ethiopia. Int. J. Adv. Res. Biol. Sci. 12(4): 31-40.
DOI: http://dx.doi.org/10.22192/ijarbs.2025.12.04.005