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Pot size influence on the growth of eucalyptus species nursery seedlings

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Abstract

Different pot sizes are used to raise nursery seedlings and these determine the early growth rate of different species of seedlings. This experiment was set up to determine the best pot size for 2 eucalyptus species namely; *E. saligna* and *E. grandis*. The experiment was laid down as a Randomized Complete Block Design (RCBD) with 8 treatments replicated 3 times. Treatments comprised of four different pot sizes namely; large (9 by 20), medium (8 by 19), small (7 by 13) and smallest (6 by 10) cm respectively based on volumes, as well as the two eucalyptus species. The experiment was carried out for a period of 6 months during 2017 and 2018 in Egerton University tree nursery. One way ANOVA was performed on the measured variables using Genstat statistical package while the means were separated using Standard Error Deviation (SED) at P< 0.05. The results revealed that the large and medium pots showed significantly higher growth in shoot, root and foliage in most of the variables measured compared with small and the smallest pot sizes. Similarly, large and medium size pots showed almost similar response in most of the variables with little significant between them and similar trend was also repeated between the small and smallest pot sizes. On the other hand, both *E. saligna* and *E. grandis* showed similar growth in all the variables except in the number of branches whereby the former was significantly (P< 0.05) higher (8.69) compared with the latter (6.65). The larger pots contained a higher soil and water volume (1272 cm^3) which supported better and healthy seedling growth as compared to the smaller pots whereby seedlings were stunted. This was shown by the latter being lower by 50% in shoot, root and total plant biomass compared with the former. It is therefore recommended to use medium sized pots to raise eucalyptus seedlings in the nursery since they are more economical and do not compromise the growth of seedlings.

Keywords: *Eucalyptus*; Foliage; Roots; Seedling growth; Nursery

1 Introduction

Eucalyptus is an evergreen flowering tree/shrub from the family of Myrtaceae, sub-family Myrotidea [1]. It is a hardwood planted widely globally for their antibacterial, insect repellent, cosmetics, anti-viral, pharmaceutical, wood purposes, nutraceutical and anti-fungal properties. The plant is fast growing [2] hence is a good source of wood and oil [3]. It tolerate diverse edaphic conditions, grows fast (10 years or less), source of wood to industries and is also used in infrastructural developments [4].

Approximately 700-800 species of eucalyptus have been identified globally [1, 4, 3]. Australia has about 700 species of eucalyptus while Brazil is the largest producer with a cultivated area of 7.5 million ha [5]. It was outlined by Del *et al.* [6] as the most widely planted genera with over 10 million ha in the tropics. In Kenya, Eucalyptus species were introduced as early as 1902 by the colonial government to provide fuel wood for Kenyan-Uganda railway locomotives [7]. Due to its fast growth rate, convenience and multipurpose, the genus has spread in all agro-ecological zones in Kenya [2, 4, 8].

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Eucalyptus was introduced in East Africa late 19th [2] and early 20th century in Ethiopia, Rwanda, Uganda, Kenya and Sudan. By 1970s, the area of eucalyptus in the 5 countries was at 95,684 ha while the largest plantations during that period were in Ethiopia (42,300 ha) and Rwanda (23,000 ha) [1]. Since 1990s, there has been upswing in eucalyptus plantations in East Africa, resulting into adoption of the genus in agroforestry [2] to meet the demand of the growing human population [1, 4]. This wide expansion was associated with promotion by some international organizations such as Food and Agriculture Organization (FAO) to improve resource base for renewable energy. Forest officers therefore participated in this by offering seedlings to small scale farmers to plant. However, there were no proper guidelines given on how and where the species was to be planted. This resulted into rising plantations along water bodies leading to receding/drying up of some water sources [1, 9].

There has been increase in eucalyptus plantations in most countries in Africa, Kenya included [2] which has contributed to regeneration of indigenous woody species hence fostering ecosystem. This is because the species has scattered canopy which allows for light penetration to the ground compared to other species such as *Cupressus lusitanica.* Additionally, eucalyptus provide a good habitat for most bird species which contribute to seed dispersal hence enhance biodiversity [1]. Some species such as *E. globulus* have been used to drain swampy areas through their roots hence abate other problems such as malaria prevalence [1].

Many species of eucalyptus have been introduced in Kenya and by 1950's, about 70 species were introduced but only a few are used as timber hence narrowing further the species. Furthermore, 100 species are currently being planted in Kenya [7]. Most of these were subjected to extensive research and currently less than 20 species have been recommended for wide scale planting. The four primary species of eucalyptus mostly planted in Kenya entails; *E. grandis, E.saligna, E. camaldulensis*. and *E. globulus* [7]. The area under eucalyptus species in the country is estimated to be about 100,000 hectares of plantations, 15,000 ha in gazetted forests, about 35,000 ha planted by private companies and 50,000 ha by farmers.

The government promoted the planting of *Eucalyptus spp*. with the increasing demand for Wood products [2, 10], which culminated in the introduction of high-yielding, shorter-rotation varieties [8] through biotechnology between 1997 and 2003. The major species planted in Kenya was *E. saligna* (Blue gum) at the western parts of Kenya [7]. However, in 1998, *E. grandis* (Rose or flooded gum) hybrids were introduced in the highlands. In addition, the species has been producing well compared with the other species; its mean annual increment in volume has been from 30 m^3ha^{-1} to 50 m^3ha^{-1} [11, 10]. *E. grandis* is the mostly grown species in Kenya since it does well both in flooded and well drained soils altitude being 1,600 to 2,200 m asl. However, *E. saligna* has been the mostly planted species in agroforestry in Kenya [8]. *E saligna* has moderate rooting and does well only in well drained soils at an altitude of 1,600 to 2,500 m asl and rainfall of ≥ 1,000 mm annually [7]. It is estimated that Kenya earns approximately Kshs. 30 billion from eucalyptus farming implying that it is a good source of income to small farmers and the nation at large [2, 4].

A study by Rocha *et al.* [12] reported that *E. grandis* can also adapt well under low water conditions and proceed with their growth processes. This is because they have adaptation strategies to reduce water losses through their leaves [13]. Therefore, the modifications can be attributed to modify volumetric production in stem biomass. Additionally, the authors report an increase in the volume of *E. saligna* in Brazil which is attributed to increased soil fertility and less hostile climate which promote biomass increment. Therefore, woody density and radial growth are related to climate of a region [12].

The same results are reported by Vivas *et al.* [13] that the growth of *E. grandis* is influenced by the environmental variations. Another study done on *E. grandis* in Uruguay show that the species record the least dbh among other three species. Moreover, there is increased height due to competition for light hence slender diameter but with increased density [14]. However, Kenya Forest Research Institute (KEFRI) report a good volumetric increase in *E. grandis* (30 m^3ha^{-1} to 50 m^3ha^{-1}) [10].

Studies in Angola by Delgado-Matas and Pukkala [15] reported that *E. saligna* has the highest growth in stand basal area and mean annual increment before 10 years while *E. grandis* show slower growth at the young stages but continue to grow for a long period. However, the authors report that both *E. grandis* and *E. saligna* have great performance with yearly growth rate of 40 m^3ha^{-1} [15]. Work by Kahunyo [16] record that these 2 species have similar diameter and volume at 6 years in most Kenyan sites.

However, further studies show that *E. grandis* hybrids and provenances have higher annual growth (60 m^3 per ha) compared with *E. saligna* (50 m^3 per ha) [15]. Moreover, it is reported that *E. grandis* have the highest species mean height while *E. saligna* have the highest stand basal area and volume [15]. However, *E. grandis* report the highest survival rates because they easily adapt to the changing environment [12].

Currently there is scanty knowledge on the ideal pot size for raising eucalyptus seedlings in the nursery hence the need for this study. Pot size is a major factor considered in growing good healthy seedlings [17]. Additionally, pot type and shape also influences seedling growth as the shape affects root development and expansion [11,18]. High quality seedlings therefore, result into improved field performance and due to ideal plant height and root development which acquires higher number of fibrous roots [19].

Moreover, big pot sizes results into increased seedling height hence enhanced growth compared with small pots [20]. This could be because large pot sizes avail more nutrients, water and space for root development [11, 19]. On the other hand, potted seedlings have become more favored over bare root method in many reforestation projects [21] as well as in private farms for various reasons such as better survival and out-planting during any time of the year and especially when the soil moisture is enough [18].

Different container sizes alters the rooting volume of the plants, basal girth and branches [11] which can greatly influence plant growth due to reduced space for root elongation and expansion [20, 19]**.** In general, as the container size increases, also leaf area, shoot and root biomass increases as well [17, 21]. Above ground and below ground plant organs are closely interrelated in their growth rates. Roots depend on leaves for food manufacture while shoots and leaves rely on the below ground parts for absorption of water, nutrients and as well as support [11, 20].

The balance between roots and shoots can be upset when the former system is reduced in a small rooting volume resulting to stunted plant growth [11]. Therefore, large pot sizes are known to help seedlings to grow over 40% larger [17]. Previous findings report that large pot sizes increase biomass yield by at 43% due to improved photosynthesis caused by large leaves [11]. According to Agonafer *et al*. [21], large pots shows significantly higher root length and root biomass in *Sesbania sesban* seedlings.

Therefore, pots improve the survival of most seedlings during transportation for transplanting [21]. This helps in reducing breakage of roots hence increased survival once planted [17]. The sizes also allow for root expansion and access to more nutrients and water resulting into increase in stem and height development [22]. Therefore, planting in pots is best for eucalyptus among other plants during nursery period [19].

2 Material and methods

2.1 Study site

The study was conducted at Agroforestry tree nursery, Egerton University, Kenya. Egerton University is located in Njoro approximately 25 km southwest of Nakuru town located approximately 182 kilometers, by road, northwest of Nairobi. The study site lies on a latitude of 0°22'11.0"S, Longitude 35°55'58.0"E and an altitude of 2,238 m above sea level [23].

The area falls in agro-ecological zone Lower Highland 3. The experimental site receives mean annual rainfall of 1,200 mm. The distribution of rain is bimodal with long rains between April and August and short rains between October and December annually. The temperatures in the field range between 10.2 and 22.0°C (24). Soils at the site are mollic andosols [23].

2.2 Experimental design

The experiment was laid down as a Randomized Complete Block Design (RCBD) with 8 treatments replicated 3 times [19]. Treatments comprised of four different pot sizes with their corresponding width and lengths in centimeters as follows: large (9 by 20), medium (8 by19), small (7 by 13) and smallest (6 by 10) as well as two eucalyptus species namely; *Eucalyptus grandis* and *Eucalyptus saligna*.

The volume of the pots was calculated using the following formula: $\prod xd^2h$ divided by 4. Large pot size (Volume=1272 cm^3) was 1.3, 2.5 and 4.5 times bigger compared with medium, small and smallest pot sizes respectively. Forest soil mixture was used for potting and 15 pots were used per each treatment per replicate while seven plants were randomly selected for sampling. The experiment was carried out from September 2017 to March 2018 for a period of 6 months.

The variables measured included; height, root collar diameter, 3rd internode length, number of leaves and branches, leaf length and width, root length, shoot, root and total biomass as well as seedling stem volume (SSV) = $\prod$ x d^2h divided by 6; where diameter and height are in centimeters.

2.3 Data analysis

Analysis of variance (one-way ANOVA) of the measured variables was done using Genstat statistics [25] while the means were separated at P≤ 0.05 using Standard Error Deviation (SED).

3 Results and discussion

3.1 Effect of varying pot sizes and *Eucalyptus* species on shoot growth of nursery seedlings

The results showed that large pot sizes had significantly (P≤ 0.05) higher growth in all the shoot variables compared with small pots (Table 1).

Table 1 Effect of varying pot sizes and Eucalyptus species on shoot growth of nursery seedlings

Pot size	Pot diameter x length (cm)	Pot volume (cm^3)	Height (cm)	3rd internode length (mm)	Number of branches	Seedling stem volume (cm^3)	Shoot biomass (g)	Total plant biomass (g)
Large	9x20	1272	39.32a	3.90a	10.48a	5.53a	5.60a	8.53a
Medium	8x19	955	37.68b	3.85ab	9.28a	4.92a	4.87b	7.70a
Small	7x13	500	34.35c	3.33b	6.45b	2.70b	2.23c	3.68b
Smallest	6x10	283	37.75b	3.45ab	4.47c	3.08b	2.27c	3.82b
Species								
Eucalyptus grandis			37.55a	3.68a	6.65b	3.91a	3.83a	5.93a
Eucalyptus saligna			37.00a	3.59a	8.69a	5.43a	3.66a	5.93a
Cv%			2.8	11.6	17	12.5	11.1	14.2
Sed			0.6	0.24	0.75	0.29	0.24	0.49

Means with different superscript letters within a column differed significantly at P≤0.05 using SED.

Similar results were reported by Kinyua [26] for jojoba, James *et al.* [19] for *Eucalyptus torelliana* [19], Salisu *et al*. [11] who reported that large pot sizes increased stem diameter, Mariotti *et al*. [22] for seed vigor on indigenous tree species; hence were in agreement with the current findings which showed that seedlings raised in larger pots produced the largest seedlings [21, 17].

Further results showed a similar trend in height and shoot biomass where large pots were significantly higher [11, 22] compared with medium ones [20]. Similarly, medium pots showed significantly superior growth in number of branches, SSV, shoot biomass and total plant biomass compared with small and also smallest pots [19]. It was logical to attribute the increases in dry weights and plant heights from increased pot size to increased soil volumes and nutrient uptake in larger ones leading to increased growth rates in such containers hence congruent to the findings by James *et al.* [19].

Furthermore, a similar report was given by other authors that large pot sizes increase shoot and root development due to availed resources such as nutrient and water [22]; unlike small pots which restricts resource availability hence stunted seedlings [11]. Under suitable conditions, there was consequently better development of primary shoots leading to taller plants among other shoot parameter [17, 20].

A study by Salisu *et al*. [11] reported significantly higher shoot and root biomass in rubber seedlings raised in large pots [20] compared with small pots and this was consistent with the current findings [17]. Other similar studies were reported by James *et al.* [19] of increased shoot and root growth in large pot sizes thus corroborated with the findings again from Agonafer *et al.* [21]. The authors also reported that the rate of seedling growth in the pot sizes depend on the type of species to be planted [11]. This could be because some species have large root system, others shallow while others deep and elongated roots.

Small pots on the other hand, caused root restriction lowering water and nutrient uptake resulting into reduced plant biomass as a consequence of reduced photosynthetic rate [11, 19]. Small pots led to root restriction which in turn reduced canopy growth. Additionally, small pots inhibited root growth leading to poor growth [11]. As a result, small pots allowed for less root expansion, reduce the number of secondary shoots and total height of all the shoots [21, 22]. Root restriction reduces dry matter production but it does not cause nutrient deficiency [19]. However, large pots allow for longer tap root in the nursery which improves seedling anchorage [20].

With regard to species, results showed that *E. saligna* had significantly higher number of branches (8.69) compared with *E. grandis* (6.65), however, there were no other significant differences observed in all the other shoot variables measured. This showed that young eucalyptus seedlings of *E. saligna* and *E. grandis* had relatively similar growth in the nursery. The results were consistent with earlier findings by Delgado-Matas and Pukkala [15], who reported that *E. saligna* had better growth rate during young stages compared with *E. grandis*, however, hybrids of the latter performed better than the original *E. saligna* in the highlands. Earlier work by Kahunyo [16] also showed that these 2 species had a similar performance at 6 years of age.

3.2 Effect of different pot sizes and *Eucalyptus* species on root growth of nursery seedlings

Large pots showed significantly higher root growth (P≤0.05) in all the variables compared with small pots, except root to shoot ratio which was similar in all the pot sizes (Table 2). Similarly, large pots showed significantly higher root length (38.6 cm) compared with medium pots (32.20 cm), while small pots (23.57 cm) were also significantly higher compared with the smallest ones (19.03 cm).

Table 2 Effect of different pot sizes and Eucalyptus species on root growth of nursery seedlings

Pot size	**Pot diameter x length (cm)**	**Pot volume (cm^3)**	**Root collar diameter (mm)**	**Root length (cm)**	**Root biomass (g)**	**Root: shoot ratio**
Large	9x20	1272	5.20a	38.60a	2.93a	0.53a
Medium	8x19	955	4.98a	32.22b	2.83a	0.58a
Small	7x13	500	3.88b	23.57c	1.45b	0.65a
Smallest	6x10	283	3.95b	19.03d	1.55b	0.72a
Species						
Eucalyptus grandis			4.41a	28.70a	2.11a	0.59a
Eucalyptus saligna			4.60a	28.01a	2.27a	0.65a
Cv%			6	7.9	27.7	29.2
Sed			0.16	1.21	0.35	0.1

Means with different superscript letters within a column differed significantly at P≤0.05 using SED.

Root growth was directly and positively correlated with pot size [22]. This could be due to large soil and water volume that supported healthy growth of seedlings [20, 22]. These findings corroborate with earlier work by Agonafer *et al*. [21] who reported higher root weight and length in large pots compared with small pots for sesbania seedlings.

The large root system contained in bigger pots supplied water and nutrient requirements of their relatively small shoot [19, 20] and this was considered a desirable character in arid lands, and could be applied as an adaptation strategy to climate change. Balanced larger seedlings achieved higher survival especially in arid environments [12, 11]. Moreover, bigger seedlings had a higher survival rates and could do well in semi-arid environments due to their improved vigor [21]. Shoot and root development of walnut seedlings was more limited by pot diameter than depth [18, 22], however this was not investigated by the current research.

A study done on *Cajanus cajan* also reported that large containers provide for enough root expansion hence higher root to shoot ratio compared with small containers with higher shoot to root ratio. Additionally, the authors reported that large pot sizes resulted into more seedlings with increased growth rate [21]. This could be related to the availability of nutrients and moisture contained in the soil in such containers [19, 20].

3.3 Effect of different pot sizes and eucalyptus species on foliage growth of nursery seedlings

Large pots showed significantly (P≤0.05) higher number of leaves (51.73) compared with medium pots (46.18), while small and smallest pots were significantly lower (30.37 and 34.52 respectively) (Table 3). Similarly, large and medium pots showed significantly higher leaf length and width compared with small pots.

Table 3 Effect of different pot sizes and eucalyptus species on foliage growth of nursery seedlings

Pot size	Pot diameter x length (cm)	Pot volume (cm^3)	Number of leaves	Leaf length (cm)	Leaf width (cm)
Large	9x20	1272	51.73a	6.70ab	2.88a
Medium	8x19	955	46.18b	6.92a	2.92a
Small	7x13	500	30.37c	5.97c	2.48b
Smallest	6x10	283	34.52c	6.10bc	2.58ab
Species					
Eucalyptus grandis			39.17a	6.31a	2.78a
Eucalyptus saligna			42.22a	6.53a	2.66a
Cv%			9.2	7.69	9.9
Sed			2.17	0.29	0.16

Means with different superscript letters within a column differed significantly at P≤0.05 using SED.

Generally, results showed that pot sizes affected number of leaves and leaf width positively [19]. Moreover, other previous findings reported that large pot sizes recorded large elongated leaves compared with the small pots [21]. The current study corroborates with studies by Kinyua [26] who reported that small pots reduced leaf size of seedlings. Other findings also reported the same results that pot size influenced seedling growth and development in nurseries [11, 17].

Plant vegetative traits increase correlated with large pots as well as leaf nutrient levels [20], while small pots reduce dry matter of roots, stem, leaves and fruits [22] . Similar report was given by Agonafer *et al.* [21] who reported that large pot sizes resulted into increased shoot growth and development. This could be related to the availability of nutrients and moisture availed in large pot sizes compared with small ones [19, 22]

4 Conclusion

Large pots supported healthy growth of seedlings in shoot, foliage and root variables while small pots led to restricted and stunted growth. Large pots were almost similar to medium ones in most variables. Among the two eucalyptus species tested. Similar results were recorded in all the variables except in the number of branches where *E. saligna* had significantly more branches compared with *E. grandis,* however, this did not affect the overall plant biomass.

Recommendations

It is therefore recommended that medium sized pots can be used to raise nursery eucalyptus seedlings since they are more economical and do not compromise the growth of seedlings. Eucalyptus seedlings also take only a short period (4 to 5 months) in the nursery hence do not require large pots.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors wish to state that there is no conflict of interest as pertaining to the current paper.

Statement of ethical approval

The present research work did not contain any studies performed on animals/humans' subject by any of the authors.

References

[1] Bayle GK. Ecological and social impacts of eucalyptus tree plantation on the environment. Journal of Biodiversity Conservation and Bioresource Management. 13 Jul 2019; 5(1): 93–104.

[2] Kluthe BG, Chen D. Eucalyptus sp. at the Intersection of Environment and Culture in Kenya. Ethnobiology Letters. 2017; 8(1): 15–22.

[3] Salehi B, Sharifi-Rad J, Quispe C, Llaique H, Villalobos M, Smeriglio A, et al. Insights into Eucalyptus genus chemical constituents, biological activities and health-promoting effects. Trends in Food Science & Technology. 1 Sep 2019; 91: 609–24.

[4] Mutitu* E. Mitigation Measures for Invasive Insect Pests on Eucalyptus Spp. in East Africa: A Review. African Phytosanitary Journal. 4 Mar 2022; 3(1): 38–46.

[5] Elli EF, Sentelhas PC, Bender FD. Impacts and uncertainties of climate change projections on Eucalyptus plantations productivity across Brazil. Forest Ecology and Management. 15 Oct 2020; 474: 118365.

[6] Del Lungo A, Ball JB, Carle JB. Global planted forests thematic study: results and analysis. Planted forests and trees working paper 38. FAO, Rome. 2010.

[7]

[8] Garrett KBM. Eucalyptus in Kenya; Impacts on Environment and Society. Graduate Theses and Dissertations Retrieved from https://scholarworks.uark.edu/etd/1661, 2016.

[9] C BN, N MM, N KJ, P H, N NP, H H, Compartmentalized Allometric Equation for estimating volume and biomass of eucalyptus in agroforestry systems in Kenya. East African Agricultural and Forestry Journal [Internet]. 20; 84(1).

[10] Hohenthal J, Räsänen M, Minoia P. Political ecology of asymmetric ecological knowledges: diverging views on the eucalyptus-water nexus in the Taita Hills, Kenya. Journal of Political Ecology [Internet]. 3 Jan 2018.

[11] Kenya Forest Research Institute (KEFRI). A guide to Eucalyptus tree farming in Kenya. Success stories. Farmers' trend. - Google Search [Internet]. 2019.

[12] Salisu MA, Sulaiman Z, Samad MYA, Kolapo OK. Effect of various types and size of container on growth and root morphology of rubber (Hevea Brasiliensis Mull. Arg.). IJSTR. 2018; 7: 21–7.

[13] Rocha SMG, Vidaurre GB, Pezzopane JEM, Almeida MNF, Carneiro RL, Campoe OC, et al. Influence of climatic variations on production, biomass and density of wood in eucalyptus clones of different species. Forest Ecology and Management. 1 Oct 2020; 473: 118290.

[14] Vivas M, Rolo V, Wingfield MJ, Slippers B. Maternal environment regulates morphological and physiological traits in Eucalyptus grandis. Forest Ecology and Management. 15 Jan 2019; 432: 631–6.

[15] Resquin F, Navarro-Cerrillo RM, Rachid-Casnati C, Hirigoyen A, Carrasco-Letelier L, Duque-Lazo J. Allometry, Growth and Survival of Three Eucalyptus Species (Eucalyptus benthamii Maiden and Cambage, E. dunnii Maiden and E. grandis Hill ex Maiden) in High-Density Plantations in Uruguay. Forests. Dec 2018; 9(12): 745.

[16] Delgado-Matas C, Pukkala T. Comparison of the Growth of Six Eucalyptus Species in Angola. International Journal of Forestry Research. 4 Sep 2011; 2011: e980259.

[17] Kahunyo SW. Evaluation of growth performance of Eucalyptus tree hybrids planted in various agro-climatic areas in Kenya [PhD Thesis]. Dissertation for Award of MSc Degree at Kenyatta University, Nairobi, Kenya. 2008.

[18] Magar AP, Nandede BM, Chilur R, Gaikwad BB, Khadatkar A. Optimization of growing media and pot size for vegetable seedlings grown in cylindrical paper pots using response surface methodology, Journal of Plant Nutrition, 2022, 45:11, 1712-1721,

[19] Khurram S, Burney OT, Morrissey RC, Jacobs DF. Bottles to trees: Plastic beverage bottles as an alternative nursery growing container for reforestation in developing countries. Min XJ, editor. PLoS ONE. 31 May 2017; 12(5): e0177904.

[20] James RO, Akorede AA, Abimbola AI, Omoh OP. Effect of Organic Manure and Potting Media on Germination and Early Growth of Eucalyptus torelliana F. Muell. American Journal of Agriculture and Forestry. 2020; 8(4): 100–7.

[21] Abera B, Derero A, Waktole S, Yilma G. Effect of pot size and growing media on seedling vigour of four indigenous tree species under semi-arid climatic conditions. Forests, Trees and Livelihoods. 2 Jan 2018; 27(1): 61–7.

[22] Agonafer H, Tura F, Kelil S, Negeyo D, Taye S. Evaluation of the Effect of Different Pot Sizes and Growing Media on the Seedling Growth Morphology of Cajanus Cajan and Sesbania Sesban in Dryland Areas, Southern Parts of Ethiopia. 19 Sep 2020.

[23] Mariotti B, Maltoni A, Jacobs DF, Tani A. Container effects on growth and biomass allocation in Quercus robur and Juglans regia seedlings. Scandinavian Journal of Forest Research.4 Jul 2015; 30(5): 401–15.

[24] Inoti SK, Cherop D. Appropriate watering interval for Prunus africana nursery seedlings in Egerton University, Njoro, Kenya. International Journal of Scientific Research Updates. 2022; 3(1): 34–39.

[25] Ngetich KF, Mucheru-Muna M, Mugwe JN, Shisanya CA, Mugendi DN. Length of growing season, rainfall temporal distribution, onset and cessation dates in the Kenyan highlands. Agricultural and Forest Meteorology. 15 May 2014; 188: 24–32.

[26] Genstat. General statistical software. Learning and Development Centre Resource. Warwick University, UK. - Google Search [Internet]. 2013.

[27] Kinyua, I.S. Ideal pot size for raising jojoba nursery seedlings in semi-arid areas of Kenya. International Journal of Development and Sustainability. 2017; 6(12): 1946-1954.