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Comparative growth and dry matter accumulation in selected tree species in response to quarry dust media amendments

Joyce Kemunto Ayusa*, John Bosco Mukundi and Aggrey Ochieng' Adimo

Department of Landscape and Environmental Sciences, School of Agriculture and Environmental Sciences, Jomo Kenyatta University of Agriculture and Technology, P. O. Box 62000-00200, Nairobi, Kenya.

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Field and laboratory trials were conducted to assess the effect of quarry dust amendments media on plant growth (biomass) of various selected tree species for re-vegetation purposes of post quarry sites in Ndurugu, Kiambu-Kenya. A randomized complete block design experiment was piloted with two-month-old nursery established seedlings of four tree species (*Acacia abyssinica, Casuarina equisetifolia, Eucalyptus grandis* and *Schinus molle*) planted in four different media treatments. The media treatments were quarry dust (QD), and quarry dust amendments of a combination of quarry dust with red soil (QD+RS), with manure (QD+MN), and with forest soil (QD+FS), in a ratio of 2:1. Destructive sampling was done in three phases after the third, sixth, and ninth months of transplanting. Measurements for tree height, fresh and dry weights were done bi-weekly in the field and laboratory. Analysis of variance (ANOVA) was conducted, and results showed a substantial difference in time-species interaction on belowground, aboveground biomass, and root shoot ratio, at p ≤ 0.05. Generally, the results obtained from the research study point out that quarry dust-manure combination has the prospective to influence the growth of the plant species favorably. The medium can be recommended for the re-vegetation process in post quarry sites in Ndarugu, Kenya.

Key words: Elite trees, quarry dust, plant biomass, re-vegetation, root shoot ratio.

INTRODUCTION

Quarrying is among the most embraced economic ventures that alter natural landscapes in many parts of the world, leading to volumes of waste discharges that pose severe pollution hazards to human health, environment, agriculture (Sracek et al., 2010; Likus-Cieślik et al., 2017; Festin et al., 2019), and biodiversity loss (Darwish et al., 2011). The industry has developed over time due to the increasing demand for raw materials (building stones) for the construction industry to cater for rapid urbanization experienced in our cities. In the past decades, mine and quarry sites were abandoned after extraction (Milgrom, 2008), and natural colonization allowed to take its cause. This was accomplished by enabling revegetation to take place naturally without human intervention. It resulted in a slow process that could take decades for adequate vegetation cover to be established (Hobbs, 2013).

Following quarrying activities, the outstanding impact

*Corresponding author. E-mail: ayusajoyce@gmail.com.

has shown an alteration in the landform instigated by the clearing of the existing vegetation, permanent elimination of the topsoil, and discarding of enormous quantities of waste. Previous researches have shown that quarry wastes both fine and coarse overburden materials, which are the rock and soil that are extracted to pave the way to the raw materials (Vela-Almeida et al., 2015), have been used in the economic sector. This has happened notably, in the transport and construction sector, through concrete production, highway construction (Safiuddin et al., 2010; Amin et al., 2011), production of ceramic tiles (Amin et al., 2011), making of sculpture, filling and leveling of the quarries. Recently, it has also indicated an encouraging potential as a planting and growth medium for plants (Feng et al., 2017).

This study was conducted to understand the effects of quarry dust on plant growth performance to optimize its utilization as a media component in the agriculture industry. The main objective was to determine plant growth performance and adaptability under the naturally occurring quarry dust material to enhance organic rehabilitation of quarry degraded sites.

MATERIALS AND METHODS

Study site

The experiment was piloted in the research fields of Jomo Kenyatta University of Agriculture and Technology, Main Campus, Juja. The centre of quarrying activity is located in Juja area, Kiambu County, Kenya. It is approximately 30 km North of Nairobi City, lies between longitude 36.999°E, 37.087°E and latitude 1.067°S, 1.123°S, and is 1560 m above sea level. The area covers about 40 km^2 and hosts a population of 200,000 people (KNBS, 2010). Juja receives long rains between March and May, while short rains are received between October and December. The main socio-economic activities include quarrying for commercial activities and agriculture for both cash crop and subsistence farming, which include coffee farming, horticulture, and cereals. The quarries are distributed on both sides of the Thika superhighway that make transportation of the by-products easy.

Plants selection

In this study, *A. abyssinica, C. equisetifolia, E. grandis,* and *S. molle,* were selected because of their relative tolerance to both biotic and abiotic stress. Research studies have also found the species play a significant role in improving soil stabilization, controlling soil erosion by protecting against wind and, improving microclimatic conditions. *A. abyssinica* is a native species in the research area. It was chosen because it is a nitrogen-fixing species, and has deep roots that can penetrate over a wide area for water collection (Coe and Beetle, 1991). *C. equisetifolia* was considered because it is a drought-resistant plant and acts as a host to several microorganisms that tend to fix atmospheric nitrogen (Anud, 2008). The species has positively been used in limestone quarries rehabilitation at Bamburi, Mombasa (Haller, 1995; Gathuru, 2012). *S. molle* being a fast-growing, evergreen, and drought-resistant tree, was considered because it can do well in all climates. *E. grandis* were chosen because their seeds can be propagated easily, and they offer economically sustainable products. Also, their roots can grow successfully on a wide variety of soils.

Plant establishment and experimental layout

A. abyssinica, C. equisetifolia, E. grandis, and *S. molle,* seeds were acquired from Kenya Forestry Research Institute (KEFRI) Seed Centre at Muguga. The seeds were germinated following recommended pre-treatment procedures to break seed dormancy. *A. abyssinica* seeds were submerged in hot water and allowed to gradually cool for at least twelve hours, *S. molle* seeds were immersed in cold water for twelve hours. While *C. equisetifolia, E. grandis* seeds did not require any pre-treatment and were established directly. After pre-treatment procedures, the seeds were planted in troughs filled with a 2:1 mixture of red soil and manure for seedling emergence and establishment.

The factorial experiment was set in the horticultural demonstration field with treatments set in a randomized complete block design (RCBD) with three replications. Recent products of stone mining, quarry dust was dug from the overburden deposits from the neighboring Ndarugu quarry sites and delivered to the experimental site for use in growth media preparation. The media treatments prepared were; (i) quarry dust (QD), (ii) a combination of quarry dust with red soil (QD+RS), a combination of quarry dust with manure (QD+MN) and a combination of quarry dust with forest soil (QD+FS) all in ratio of 2:1. About 40 L of the well-mixed media was put in high strength pots for planting with individual plants. The plant species-media treatments were randomly assigned. Each experimental element consisted of six potted plants. Thus 24 (6*4) plants per species in one replication (Figure 1) and similar illustration was done for the other plants' species in the three replications. The four test plant species were transplanted into the pots after two months of seedling establishment. The necessary plant maintenance procedures, such as weeding and watering were done bi-weekly to ensure the healthy and uniform growth of the plant species.

Data collection

Plants were allowed to establish for three months before the first data collection exercise. Sampling was conducted in the field at three different time phases since transplanting at three months, six months, and nine months. For each experimental unit, three plant samples were picked randomly using the random numbers table. The selected plants were uprooted from the pots, dipped in water for about 30 min to remove excess soil from the roots. Plant height (H) was then determined by measuring the height of the plant right from the soil surface to the tip of the youngest leaf by use of a tape measure; root collar diameter (RCD) was measured using a vernier caliper and values recorded. The plants were then divided into the root and the shoot sections. Fresh weight for each section was measured immediately and recorded. The plants were then transferred to the laboratory and oven-dried at a temperature of 85°C for 24 h and their dry weights recorded.

Data analysis

The collected data were cleaned and input on worksheets according to treatments using Microsoft excels software. The organized data was then subjected to a one-way analysis of variance (ANOVA) using the Statistical Software Package for Social Sciences (SPSS) 23rd edition to assess differences between the media treatments and plant species. The statistical significance was determined at $p \leq 0.05$ and the means separated by the Tukey's HSD range test and Least Significant Difference (LSD).

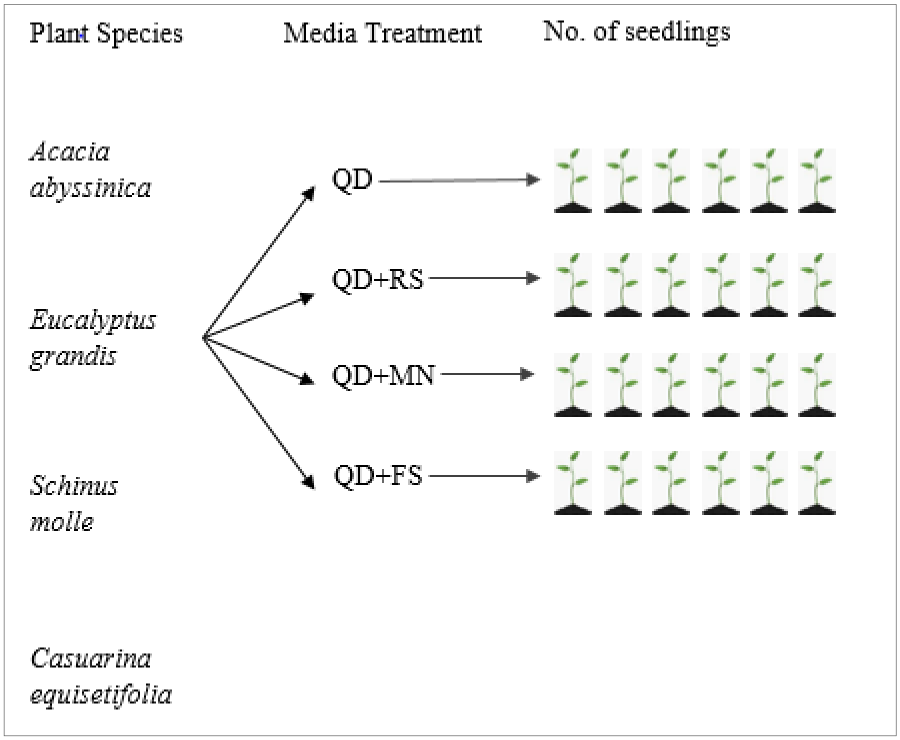

Figure 1. Experimental illustration of the plant species in different media treatments for one replication (QD= Quarry dust, QD+RS= combination of quarry dust with soil, QD+MN= combination of quarry dust with manure, QD+FS= combination of quarry dust with forest soil).

RESULTS AND DISCUSSION

Chemical composition of growth media

Quarry dust media amendments were analyzed for chemical properties and recorded, as shown in Table 1. Quarry dust had slightly above neutral pH (7.3), lowest electrical conductivity, and the highest bulk density, among other media types. Overall, quarry dust returned the lowest values for total nitrogen, carbon, phosphorus, and exchangeable cations calcium (Ca), magnesium (Mg), and potassium (K), compared to all quarry dust amendments.

Hiatt and Kyser (2000), describes quarry dust as soil with similar characteristics as argillaceous soils. The pH lenience limits of different trees differ significantly; the majority of tree species have a neutral range that is more suitable, with pH values that range from 6.3 to 7.3 (Landon, 2014). For ideal plant, growth proportion of different nutrients plays a significant role. Nitrogen is one of the macronutrients; its primary source is the breakdown and humification of organic matter. The supply dramatically influences microbial activity (Fageria and Baligar, 2005). The value of nitrogen from the quarry dust recorded a value of 0.28 translated as a medium.

The exchangeable cations (Ca, Mg, and K) measurements are done as an overall assessment of the potential fertility of soils. This is of abundant importance on nutrient uptake by the plant and soil structure (Landon, 2014). At high pH values, the presence of calcium converts phosphate to calcium phosphates and reduces the amount of free phosphorus available to trees. The outcomes of the available cations on plant growth are often intertwined. The quantities of K, Ca, and Mg with each other are essential because a surplus of either could deter the uptake of the other elements causing the deficiency, even though an individual component occurs in sufficient amounts in the soil (Forstner and Wittmann, 2012). Organic carbon in the soil predicts water-holding capacity properties of soils (Libohova et al., 2018). The C: N ratios in the soils act as indicators of the organic matter type present and the degree of humification. From the study area, the ratio was 3:2. Therefore, the ratio is not indicating the exact amount of organic matter in the soils.

Aboveground biomass

From the analysis (Table 2), there was a significant time-species interaction demonstrating a differentiated plant growth (biomass) for all the species. In the third month of

Table 1. Chemical constitution of quarry dust and media amendments.

Parameter	Units	QD	QD+RS	QD+MN	QD+FS
Soil pH		7.3	7.31	7.18	7.36
Electrical conductivity	mS/cm	0.11	0.63	0.48	0.98
Bulk Density	g/cm^3	1.05	0.86	0.88	0.86
Nitrogen	mg/g	0.28	0.42	0.33	0.37
Phosphorus	$mgkg^{-1}$	10.43	88.6	77.2	71.4
Potassium	$mgkg^{-1}$	0.02	0.284	0.268	0.276
Calcium	$mgkg^{-1}$	1.04	2.93	2.73	2.87
Carbon	%	0.42	1.98	2.02	2.09
Magnesium	$mgkg^{-1}$	0.31	0.57	0.52	0.64

QD= Quarry dust, QD+RS= combination of quarry dust with soil, QD+MN= combination of quarry dust with manure, QD+FS= combination of quarry dust with forest soil.

Table 2. ANOVA results for different media treatments on aboveground biomass for *A. abyssinica, E. grandis*, *S. molle,* and *C. equisetifolia* plant species in the three different time phases at p≤ 0.05.

		Above ground biomass					
Species	**df**	**3 Months**		**6 Months**		**9 Months**	
		F	***P*-value**	***F***	***P*-value**	***F***	***P*-value**
Acacia abyssinica	3	0.978	0.450	7.938	0.009	1.292	0.360
Eucalyptus grandis	3	2.116	0.176	20.930	<0.001	4.090	0.067
Schinus molle	3	1.350	0.325	21.880	<0.001	6.365	0.016
Casuarina equisetifolia	3	1.127	0.394	20.633	0.001	2.226	0.173

growth, there was no significant difference between media treatments in the biomass of *A. abyssinica* at p≤ 0.05. By the sixth month, QD+MN had the highest mean, slightly different from QD+RS, and significantly different from QD+FS and QD (p≤ 0.05). After the ninth month of growth, no significant difference was observed between the treatments (Figure 2a). The measured above ground biomass of *E. grandis* showed no significant difference between the other media treatments in the third month. By the sixth month, biomass for QD+MN treatment had increased twenty-fold, followed by QD+RS, which rose about eightfold, and the lowest was from QD treatment. In the ninth month, no significant difference was observed between the media treatment (Figure 2b).

S. molle species showed no substantial difference in aboveground biomass between the different media treatments as of the third month. From the results, QD+MN promoted more biomass, which was significantly different in the 6^{th} and 9^{th} months as compared to other media treatments (Figure 2c). *C. equisetifolia* species showed the least mean biomass in the third month due to its slow growth rate. At the sixth month following transplanting, QD+MN gave the highest biomass accumulation that was significantly different at p≤ 0.05, from the other media treatments. And finally, the ninth month showed no statistical difference between media treatments (Figure 2d).

Belowground biomass

The belowground growth's determinants are water and nutrients in the medium (Agathokleous et al., 2018). From the results (Table 3), in the third, sixth, and ninth months of development, *A. abyssinica* showed no statistical difference between the media treatments (Figure 3a). This shows an indication that the root mass of Acacia species was not affected by growth media. *E. grandis* species indicated no significant difference in all the media treatments in the third month of growth. QD+RS had the highest mean of 2.0 g. In the sixth month, QD+MN showed a significant increase of about 56%, hence indicating a substantially different from the other three treatments. In the ninth month, no significant difference was observed (Figure 3b).

S. molle species showed no significant difference (p≤ 0.05) between the media treatments as of the third month of growth. The 6^{th} and 9^{th} month exhibited similar results where QD+MN means were significantly different from the other treatments with means of 19.8 and 52.5 g. In the two time phases, QD recorded the lowest means of 2.7 and 7.4 g (Figure 3c). *C. equisetifolia* species showed

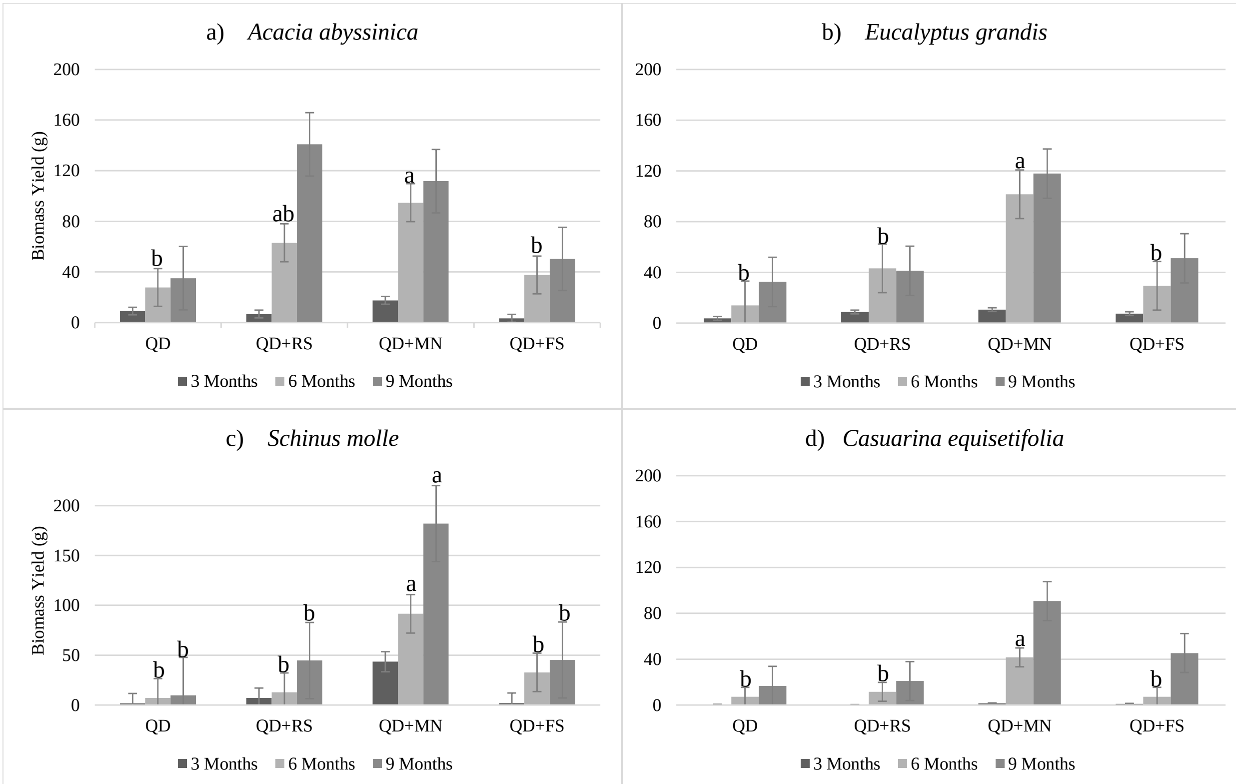

Figure 2. Effects of different media treatments on aboveground biomass for (a) *A. abyssinica* (b) *E. grandis* (c) *S. molle* (d) *C. equisetifolia* plant species in the three different time phases. Vertical bars sharing the same letter in the figure for media treatment in the different months are not significantly different at p≤ 0.05.

Table 3. ANOVA results for different media treatments on belowground biomass for *A. abyssinica, E. grandis*, *S. molle*, and *C. equisetifolia* plant species in the three different time phases at p≤ 0.05.

Below ground biomass							
Species	**df**	**3 Months**		**6 Months**		**9 Months**	
		F	***P*-value**	***F***	***P*-value**	***F***	***P*-value**
Acacia abyssinica	3	0.481	0.704	3.405	0.074	0.912	0.489
Eucalyptus grandis	3	0.488	0.699	14.317	0.001	1.241	0.374
Schinus molle	3	0.719	0.569	6.232	0.017	4.256	0.045
Casuarina equisetifolia	3	1.264	0.350	15.391	0.002	2.178	0.178

the least means in the third month; there was no significant difference (p≤ 0.05) among the media treatments. In the sixth month, growth improvement was observed with biomass mean of QD+MN being significantly different p≤ 0.05, while the ninth month showed no treatment difference (Figure 3d).

Root-shoot ratio

The plant growth and development form have a notable outcome on the root-shoot ratio (Askari et al., 2017). This root-shoot ratio then shows the plant health conditions and sensitivity to stress (Agathokleous et al., 2018). The root to shoot ratio results of the selected tree species from the analysis were observed (Table 4). *A. abyssinica* showed no statistical difference for the three phases (Figure 4a). A similar trend was observed for *E. grandis* (Figure 4b) and *S. molle* (Figure 4c). For *C. equisetifolia* in the 3rd month, there was no significant difference between the media treatments. However, for the 6th month, QD+FS was statistically different (p≤ 0.05) from the other three treatments and the 9th month, the results of the root-shoot ratios indicated no significant difference

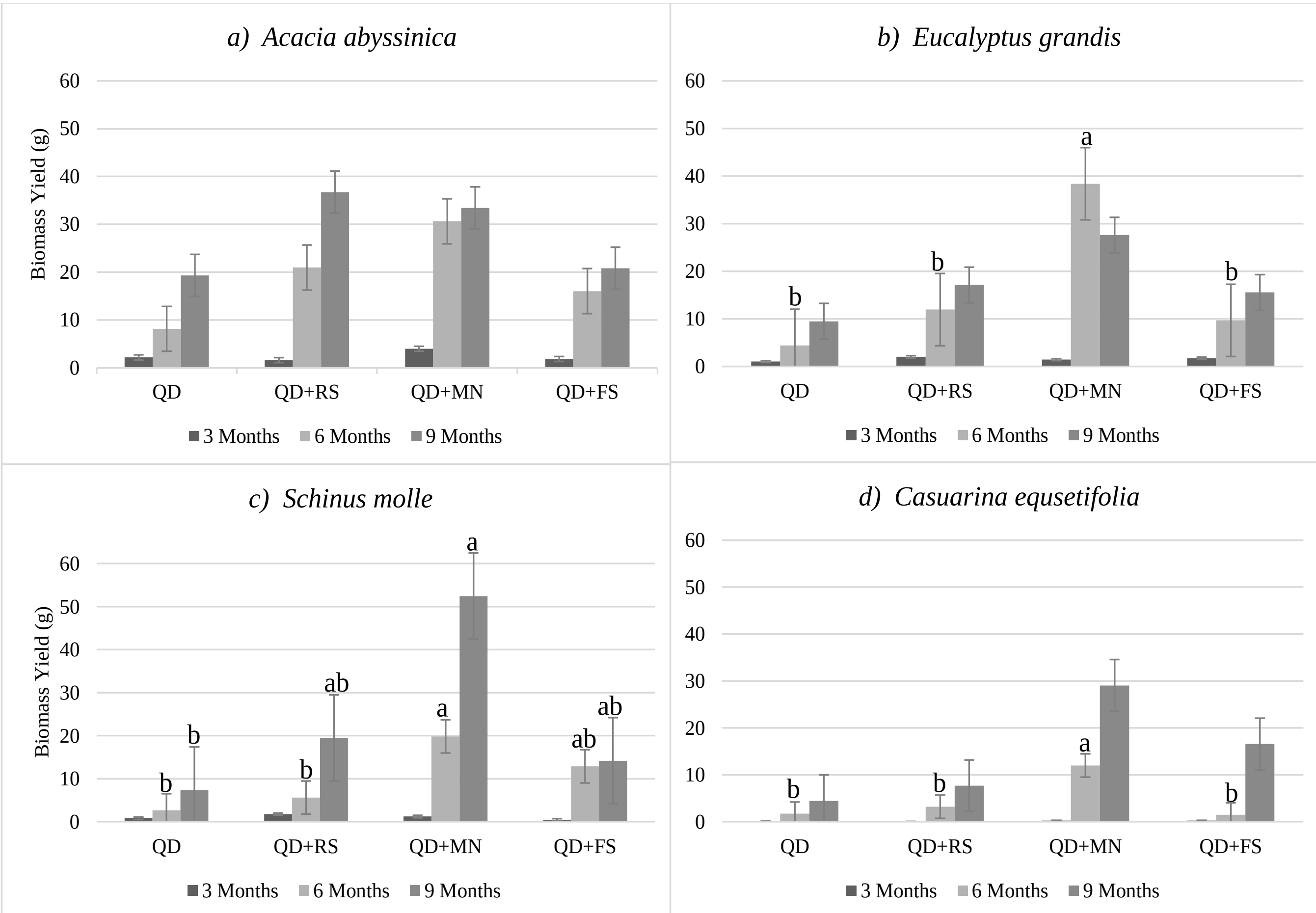

Figure 3. Effects of different media treatments on belowground biomass for (a) *A. abyssinica* (b) *E. grandis* (c) *S. molle* (d) *C. equisetifolia* plant species in the three different time phases. Bars sharing the same letter in the figure for media treatment in the different months are not significantly different at p≤ 0.05.

Table 4. ANOVA results for different media treatments on root shoot ratio for *A. abyssinica, E. grandis*, *S. molle*, and *C. equisetifolia* plant species in the three different time phases at p≤ 0.05.

		Root shoot ratio					
Species	**df**	**3 Months**		**6 Months**		**9 Months**	
		F	***P*-value**	***F***	***P*-value**	***F***	***P*-value**
Acacia abyssinica	3	0.631	0.615	0.658	0.600	0.758	0.557
Eucalyptus grandis	3	3.367	0.075	0.587	0.640	1.055	0.435
Schinus molle	3	3.257	0.080	1.038	0.426	1.027	0.431
Casuarina equisetifolia	3	1.310	0.337	8.075	0.011	1.392	0.322

for all the treatments (Figure 4d).

From the study, the root to shoot ratio of the majority of the species decreases as the phase of a tree increases, but no notable difference is observed to the growing media and environments (Marler and Willis, 1996). Plant shoots enable plants to reach required light while the root system deals with environmental stresses by scavenging for water and nutrients in the growth media. Hence the root to shoot ratio indicates the potential of supportive functions of the roots and the shoots. The belowground system's competition aptitude varies between the early and late growth phases of the tree growth (Xiang et al., 2013; Zangaro et al., 2016). It is considered that plants in the early stages of growth show higher shoot compared

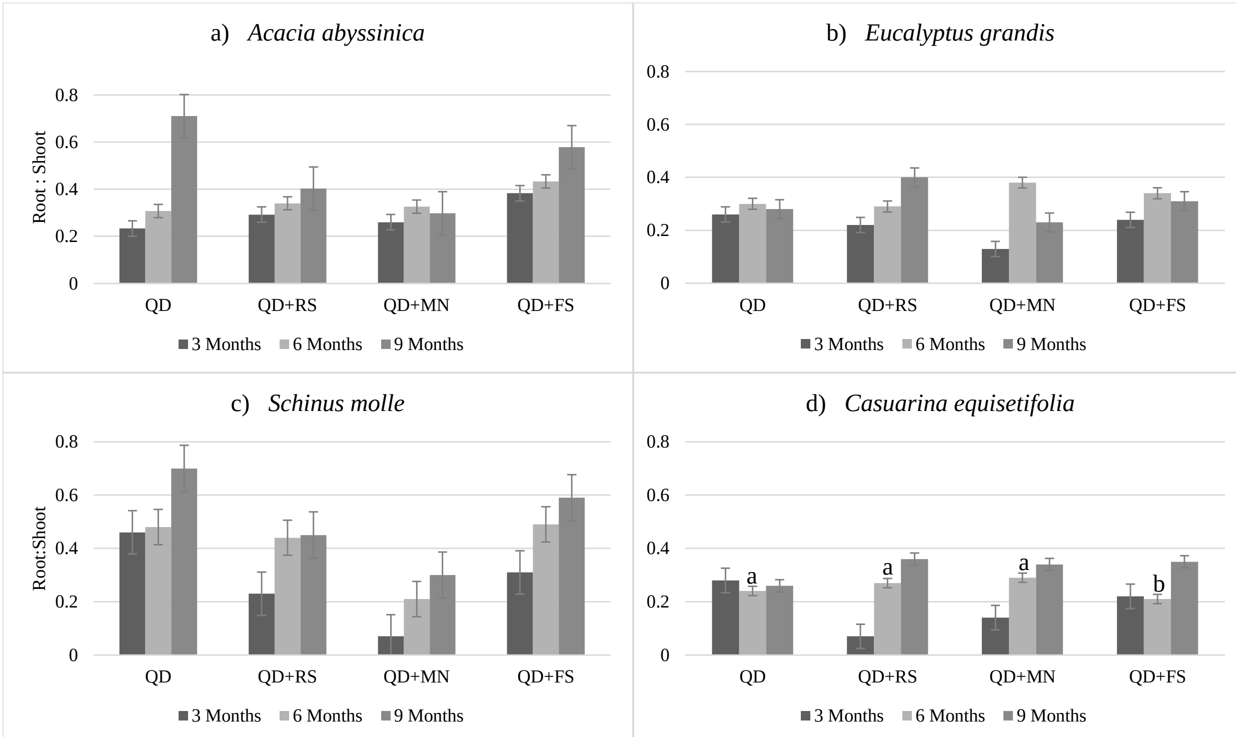

Figure 4. Effects of different media treatments on shoot root ratio for (a) *A. abyssinica* (b) *E. grandis* (c) *S. molle* (d) *C. equisetifolia* plant species in the three different time phases. Bars sharing the same letter in the figure for media treatment in the different months are not significantly different at p≤ 0.05.

to the root system (Kajimoto et al., 2006).

Conclusion

From the results, all four species performed moderately in the quarry dust substrate alone. *A. abyssinica* showed a much better response compared to the other three plant species, in both above and belowground biomass components. The acacia species is an indigenous plant species commonly occurring in the wooded grassland of dry agro-climatic zones in East Africa. It is reported to be drought-tolerant and grows well on degraded land providing a hardwood suitable for many local uses (ICRAF, 1992). These aspects of the plant could attribute to its relatively good performance on un-amended quarry dust compared to other species making it a good choice for inexpensive re-vegetating of quarried land by the landowners.

Among the media amendments, the highest growth performance was recorded in quarry dust-manure treatment for both aboveground and belowground biomass. *S. molle* benefited the most from quarry dust amendment with manure recording 94 and 85% change in above and belowground biomass, respectively. *C. equisetifolia*, *E. grandis,* and *A. abyssinica* followed in this order, in response to quarry dust amendment with manure. Thus, *S. molle* is an equal right choice of plant for re-vegetating post-quarry degraded land provided some manure is incorporated during planting. However, in all cases, the cost of amending quarry dust must be weighed against the expected value of the plantation in choosing the re-vegetation method.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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REFERENCES

Agathokleous E, Belz RG, Kitao M, Koike T, Calabrese EJ (2018). Does the root to shoot ratio show a hormetic response to stress? An ecological and environmental perspective. Journal of Forestry Research 30(5):1569-1580.

Amin SK, Youssef NF, El-Mahllawy MS, El-Abd H (2011). Utilization of Gebel Attaqa Quarry waste in the manufacture of single fast-firing ceramic wall tiles. International Journal of Environmental Science 2(2):765-780. https://doi:10.6088/ijes.00202020037

Anud BS (2008). Casuarina. Salt Tolerant, Drought Resistant Tree for Converting Unfertile Lands to Fertile Lands.

Askari Y, Soltani A, Akhavan R (2017). Assessment of root-shoot ratio biomass and carbon storage of Quercus brant ii Lindle. In the central Zagros forests of Iran. Journal of Forest Science 63(6):282-289. https://doi:10.17221/122/2015-JFS

Coe MK, Beetle HJ (1991). A Field Guide to the Acacias of Kenya. Oxford University Press.

Darwish T, Khater C, Jomaa L, Stehouwerb R, Shaban A, Hamze' M (2011). Environmental impact of quarries on natural resources in Lebanon. Land Degradation and Development 22(3):345-358. https://doi.org/10.1002/ldr.1011

Fageria NK, Baligar VC (2005). Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy 88:97-185. https://dx.doi.org/10.1016/S0065-2113(05)88004

Feng J, Zhang C, Zhao T, Zhang Q (2017). Potential harmful effects of landfill stabilized waste: semi-volatile organic compounds and salinity, A case study in Beijing, China. Environmental Earth Science 76(11):387. https://doi.org/10.1007/s12665-017-6723-5

Festin ES, Tigabu M, Chileshe MN, Syampungani S, Oden P (2019). Progresses in the restoration of post-mining landscapes in Africa. Journal of Forestry Research 30(2):381-396. https://doi:10.1007/s11676-018-0621-x

Forstner U, Wittmann GT (2012). Metal pollution in the aquatic environment. Springer Science and Business Media. https://doi.org/10.1002/iroh.19810660232

Gathuru G (2012). The performance of selected tree species in the rehabilitation of a limestone quarry at East African Portland Cement Company land Athi River, Kenya. (Doctoral dissertation).

Haller R (1995). Rehabilitation of Limestone Quarry. Mombasa, Kenya.

Hiatt EE, Kyser TK (2000). Links between depositional and diagenetic processes in basin analysis: porosity and permeability evolution in sedimentary rocks. Fluids and Basin Evolution. Toronto, Canada: Mineralogical Association of Canada.

Hobbs RJ (2013). Foundations of restoration ecology. Island Press.

International Centre for Research in Agroforestry (ICRAF). (1992). A selection of useful trees and shrubs for Kenya. ICRAF, Nairobi, Kenya.

KNBS KN (2010). The 2009 Kenya population and housing census. (Vol. 1). Nairobi: Kenya National Bureau of Statistics.

Kajimoto T, Matsuura Y, Osawa A, Abaimov AP, Zyryanova OA, Isaev AP, Yefremov DP, Mori S and Koike T (2006). Size-mass allometry and biomass allocation of two larch species growing on the continuous permafrost region in Siberia. Forest Ecology and Management 222(1-3):314-325. https://doi.org/10.1016/j.foreco.2005.10.031

Landon JR (2014). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. New York: Routledge.

Libohova Z, Seybold C, Wysocki D, Willis S, Schoeneberger P, Williams C and Owens PR (2018). Reevaluating the effects of soil organic matter and other properties on available water-holding capacity using the National Cooperative Soil Survey Characterization Database. Journal of Soil and Water Conservation 73(4):411-421. https://doi:10.2489/jswc.73.4.411

Likus-Cieślik J, Pietrzykowski M, Szostak M, Szulczewski M (2017). Spatial distribution and concentration of sulfur in relation to vegetation cover and soil properties on a reclaimed sulfur mine site (Southern Poland). Environmental monitoring and assessment 189(2):87. https://doi.org/10.1007/s10661-017-5803-z

Marler TE, Willis D (1996). Chemical or air root pruning containers improve carambola, longan, and mango seedling root morphology and initial root growth after transplanting. Journal of environmental horticulture 14:47-49.

Milgrom T (2008). Environmental aspects of rehabilitating abandoned quarries: Israel as a case study. Landscape and Urban Planning, 87(3):172-179. https://doi.org/10.1016/j.landurbplan.2008.06.007

Safiuddin M, Jumaat MZ, Salam MA, Islam MS, Hashim R (2010). Utilization of solid wastes in construction materials. International Journal of Physical Science 5(13):1952-1963.

Sracek O, Mihaljevič M, Křïbek B, Majer V, Veselovský F (2010). Geochemistry and mineralogy of Cu and Co in mine tailings at the Copperbelt, Zambia. Journal of African Earth Sciences 57(1-2):14-30. https://doi.org/10.1016/j.jafrearsci.2009.07.008

Vela-Almeida D, Brooks G, Kosoy N (2015). Setting the limits to extraction: A biophysical approach to mining activities. Ecological Economics 119:189-196. https://doi:10.1016/j.ecolecon.2015.09.001

Xiang W, Wu W, Tong J, Deng X, Tian D, Zhang L, Liu C, Peng C (2013). Differences in fine root traits between early and late-successional tree species in a Chinese subtropical forest. Forestry 89:343-351. https://doi:10.1093/forestry/cpt003

Zangaro W, Lescano LM, Matsuura EM, Rondina AB, Nogueira MA (2016). Differences between root traits of early- and late-successional trees influence belowground competition and seedling establishment. Journal of Tropical Ecology 32:300-313. https://doi:10.1017/S0266467416000274