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Full Length Research Paper

Effects of furrow dimensions on water productivity and yield of onion at small scale Irrigation Ilu Gelan district West Shoa Ethiopia

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This study was conducted at the Ilu Gelan district Western Shewa zone of Oromia Regional State to evaluate the impacts of furrow dimensions on yield and water productivity of onion. The experiment was laid out in a randomized complete block design with three treatments replicated four times. The experimental treatments including farmer practice or T1 (farmer practice with top width of 23 cm, bottom width of 13 cm and depth of 11 cm without determined flow rate), T2 (Furrow with top width of 45 cm, bottom width of 20 cm and depth of 12 cm with determined flow rate) and T3 (Furrow with top width of 35 cm, bottom width of 14 cm and depth of 10 cm with determined flow rate) having a plot size of 8 m × 5 m with spacing of 0.5 m × 1 m between plots and replications respectively. The highest application efficiency of (75.87%) was recorded under treatment T2 and the lowest application efficiency of (56.17%) was recorded from T1 that is, farmer practice when compared with other treatments. The highest distribution uniformity of (89%) was recorded from treatment T2 and lowest (81%) was from treatment T1. In terms of water productivity and yield of onion the highest values of 5.2 kg/m3 and 1952 kg/ha were recorded from T2 respectively. Similarly, lowest values 3.11 kg/m3 and 15088 kg/ha were obtained from T1 respectively. There were significance differences in plant height among all treatments at significance level of 5%. The highest (41.525 cm) was recorded from T2 and the lowest (39.275 cm) was obtained from T1. Further research covering all soil types is recommended to be more inclusive.

Key words: Furrow irrigation, furrow dimension, grain yield, irrigation efficiency, onion, water productivity.

INTRODUCTION

The sources of water for crop production are rainfall and irrigation water. The two types of agriculture seen from the perspective of water management are rain fed and irrigation agriculture which both helps to present sufficient water in the root zone for germination, evapotranspiration and nutrient observation (Dupriez and De Leener, 2002). In Ethiopia irrigation is used as complementary with rain fed during dry season. One of the irrigation methods in agriculture is furrow irrigation. This technique has been used for a variety of crops. Improving small scale farmers need to consider efficient utilization of irrigation water (Shuhuai et al., 2012). Agronomic practices have a profound effect on farm water management practices. A number of factors such as nature of cultivar, plant density, sowing time, and nutrient and water management are involved in affecting profitable yield Masoud and

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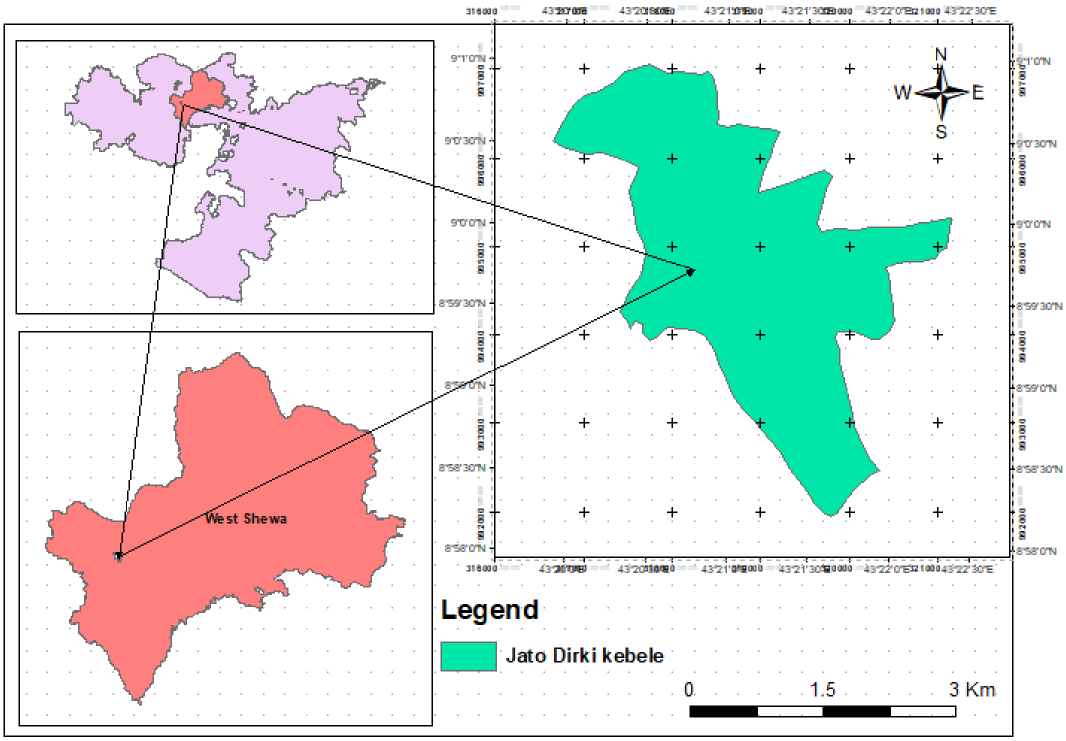

Figure 1. Location Map of the experimental site.

Ghodratolah (2010)

In the study area, farmers furrow dimensions by using animal power and local material prepared for plow. However, this material is made of different dimensions for using it at different points of the furrow length. The irrigation water diversion to the field is being done without considering design of furrow dimension. The release of high flow rate overtops the furrow section and takes off the soil resources as surface runoff which in turn reduces the nutrient of the soil. This phenomenon occurs if the furrow dimensions do not suite the incoming flow rate depending on the soil type of the area. The problem leads to erosion and frequent need of furrow construction. In other hand, application of very low flow rate results in deep percolation at furrow head while, other part of the furrow become under irrigated. Consequently, these practices are known to produce greater chance of water logging, tail water losses, salinity hazards, high yield loss and lower economical profit (Walker, 2003). Problems of irrigation water management leads to shortage of water and competitions among different agricultural and non- agricultural demands. The need of suitable water resource management is, therefore, serious concern for enhanced water use among different sectors. Proper use of furrow widths, depth, and length is one of the practices in irrigated agriculture to maximize irrigation efficiencies and enhanced crop yield as well as the water use efficiency. In addition, it can enable the users to conserve soil and water resources. This study will provide indicative information on the response of irrigation performance indicators, yield and water use efficiency of onion due to the proper furrow dimensions.

In west Shoa zone of Oromia Regional state, onion is often produced by furrow irrigating under the limited water available for irrigation and onion crop is the most common irrigated horticultural crop in the district. Farmers growing onion crop in this area have not been practicing furrow management practices. Hence furrow management practice that can improve irrigation water productivity of small scale onion producing farmers is important in the area. This study investigated the effect of different furrow dimensions on irrigation water productivity and yield and yield components.

MATERIALS AND METHODS

Experimental site description

A field experiment was carried out in 2017/2018, at Jato Derke which is administratively located in Ilu Gelan district of West Shoa Zone in the Oromia Regional State (Figure 1). This site is considered a representative site for the midland irrigation schemes of West Shoa Zone of Oromia Regional State. It is located at 08°59'51''N latitude and 37°19'49''E with an altitude of 1812 m above sea level. The minimum and maximum monthly average temperatures are 13.8 and 28.1°C, respectively. The average rainfall is around 1351 mm and this site has limited irrigation water that cover a large hectares of farmland in which onion is the

Table 1. Experimental treatment setup.

S/N	Treatment setting		Treatment statement	Code
	Furrow Dimension	Flow Rate		
1	23 cm TW,13 cm BW and 11 cm d	With Measured	Farmer practice (top width of 23 cm, bottom width of 13 cm and depth of 11 cm)	T1
2	45 cm TW, 20 cm BW and 12 d	With measured	Furrow with top width of 45 cm, bottom width of 20 cm and depth of 12 cm	T2
3	35 cm TW, 14 cm BW and 10 cm d	With measured	Furrow with top width of 35cm, bottom width of 14 cm and depth of 10 cm	T3

dominant crop grown in the command area followed by different horticultural crops.

Experimental design and management

The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. There were three levels of furrow dimensions with incoming flow rate measurement and this has a total of three treatments. The plot size was 8 m × 5 m and the distance between replication and plots were 2 and 1 m respectively. The plots in each replication were represented randomly for each treatment. The experimental field was fertilized UREA (46 Kg N ha^{-1}) and DAP (92 kg P_2O_5 ha^{-1}), (Melkasa Agricultural Research Center, 2000). The DAP was applied at basal but UREA was applied both during planting and three weeks after plating (1/3rd at basal and 2/3rd three weeks after planting). The experimental plot was ploughed three times before planting and managed carefully from weeds to minimize water and nutrient competition with crop. The variety of experimental crop was Bombay red onion variety and transplanted with spacing of 40 cm and 20 cm spacing between rows and plants, respectively (Table 1).

Furrow dimensions were made based on farmers dimensions. Most of the farmers in Ethiopia are make furrows using traditional ways of furrow making. In traditional furrow making furrows were made by local material pulled by oxen power. Furrow size made by this method is considered as farmers furrow dimension (top width of 23 cm, bottom width of 13 cm and depth of 11 cm). Other treatments were made based on the farmers furrow dimension that is, by taking above and below farmer's dimension. Furrows of T2 and T3 were closed end and the applied water was slowly infiltrated into the root zone. But un-designed or farmer practice was an open ended and the water was lost as surface runoff at the end of furrow length.

Crop water requirement and irrigation requirement

Crop water requirements (CWR) encompass the total amount of water used in evapotranspiration. Irrigation requirements (IR) refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements. CROPWAT Version 8.0 is a computer program that can calculate CWR and IR based on climatic and crop data.

Irrigation performance Indicators

Water application efficiency

Water application efficiency is a measurement of how effective the irrigation system is in storing water in the crop root zone. It is expressed as the percentage of the total volume of water delivered to the field that is stored in the root zone to meet crop evapotranspiration (ET) needs.

$$Ea = Ws/Wf \times 100 \quad (1)$$

Where, Ea = water application efficiency, %
W_s = water stored in crop root zone, cm
W_f = water delivered at the head end of the furrows, cm.

Water distribution efficiency

Water distribution efficiency is defined as the percentage of difference from unity of the ratio between the average numerical deviations from the average depth stored during the irrigation. It was determined using the following formula:

$$Ed = (1 - \bar{y}/\bar{d}) \times 100 \quad (2)$$

Where, Ed=Water distribution efficiency, %
d=Average depth of water stored in root zone along the furrow after irrigation, cm
y=Average numerical deviation from d, cm

Crop water productivity (CWP)

CWP is defined as the relationship between the amounts of crop produced or the economic value of the produce and the volume of water associated with crop production (Playa´n and Mateos, 2006). There are three dimensions of water productivity: physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net income returns from unit of water consumed, and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kumar et al., 2005). The CWP considered in this study is physical productivity defined as: Mass of produce (kg) per volume of water supplied (m^3) expressed as in Equation 3 (Playa´n and Mateos, 2006):

$$CWP = \frac{Y}{WR} \quad (3)$$

Where, CWP = Crop water productivity, (kg/ m^3),
Y= Yield of the crop, (kg/ha)
WR= Water requirement of the crop, (m^3/ha).

Yield and yield components

Stand count

Plants that successfully established in the central rows were

Table 2. Chemical properties of soil at Ilu Gelan district.

Chemical properties	Value
1. Available phosphorus (ppm)	6.546
2. pH in H_2O	6.21
3. Total nitrogen (%)	0.240
4. Electrical conductivity (ms/cm)	0.035
5. Organic matter (%)	4.803
6. Exchangeable cations (meq/100 g soil)	
a. Ca	2.553
b. Mg	1.200
c. K	0.656
d. Na	0.261
e. CEC	35.283

counted at harvest and expressed as percentage.

Plant height (cm)

This was measured from the ground to the tip of the leaves from 10 randomly selected plants at maturity.

Marketable bulb yield (t ha^{-1})

This referred to the weight of healthy and marketable bulbs that range from 20 to 160 g in weight. Bulbs below 20 g in weight were considered too small to be marketed whereas those above 160 g were considered oversized according to Lemma and Aklilu (2003). This parameter was determined from the net plot at final harvest and expressed as t ha^{-1}.

Characterization of the soil of the study site

About 0-60 cm depth of disturbed (composite) and undisturbed soil samples were collected from different points by using soil auger and core sampler respectively for the analysis of physical and chemical properties. The composite sample (after being well mixed in a bucket) of about 2 kg of the mixed sub samples (composite sample) was properly bagged, labeled and transported to the laboratory for analysis of soil chemical properties. The soil pH was measured potentiometrically with a digital pH meter in the supernatant suspension of 1:2.5 soils to water ratio. The soil electrical conductivity measurement was done using a conductivity meter at 25°C using its standard procedures. Field capacity (FC) and permanent wilting Point (PWP) of sampled soil were determined using pressure plate apparatus at 1/3 and 15 bar, respectively. The soil texture was measured from samples collected at different depths using hydrometer method. The textural class of the soil profile was determined using USDA textural triangle.

Soil sample collected from the study site was analyzed for some chemical properties such contents of Nitrogen, Phosphorus, Organic matter, and soil pH and as well as exchangeable cations.

Data analysis

The collected data were arranged and organized for the suitability of statistical analysis and finally analysis of variance (ANOVA) was performed using statistix.8 software. Least significant difference (LSD) at 5% level significance was used to make mean separation among treatments.

RESULTS AND DISCUSSION

Physical and chemical soil parameters

Laboratory analysis of particle size distribution indicated that the soil is clay in textural class throughout the soil depth with an average particle size distribution of 34% sand, 21% silt and 45% clay whereas the average gravimetric moisture content at field capacity and permanent wilting point were 33.02 and 24.8%, respectively. The value of bulk densities (1.303 gcm^{-3}) were obtained by considering the average of the 0-40 cm depth. This value is in the recommended range for crop production. The average total available water was found to be 106.8 mm/m. The pH in H_2O under this study area is ranged in optimum value as suggested by Jones (2003) (Table 2). An electric conductivity of 0.035 ms/cm was recorded which is at lower limit of saline soils, hence the soil samples are non-saline soils (Table 2). Plants growing in this area do not have the problem of absorbing water because of the lower osmotic effect of dissolved salt contents.

The total nitrogen of study area as suggested by Tekalign (1991) rated as high percent which is suitable for plant growth (Table 2). Since the plant obtains phosphorus (P) from the soil solution through its roots or root symbiosis, available P is composed of solution P plus P that enters the solution during the period used to define availability. As per the rating suggested by Jones (2003) the available P of soil of experimental field of the studied area was qualified as low (Table 2). As per the ratings recommended by Hazelton and Murphy (2007), the CEC value of the agricultural land of the present study area is in high value range.

Table 3. Irrigation efficiencies and distribution efficiency of treatments.

Treatments	Application efficiency (%)	Water distribution efficiency (%)
T1	56.17[c]	81.00[b]
T2	75.87[a]	90.50[a]
T3	69.48[b]	89.00[a]
LSD 0.05	5.6817	8.3
CV%	12.89	10.31

Means with the same letter in a column are not significantly different.

The high CEC value recorded may be attributed to the fact that soils which recorded high CEC accumulate high percent OC and has greater capacity to hold cations thereby resulted in greater potential fertility in the soil (Table 2). The value of available Ca and Mg were below the optimum range whereas that of K was within the recommended optimum range as suggested by Takuya et al. (2013) (Table 2). The organic matter was rated as medium which is suitable for crop growth (Table 2).

Irrigation efficiencies and distribution efficiency

Table 3 shows the irrigation efficiency and distribution efficiency.

Irrigation efficiencies

Results of analysis of variance revealed significant difference for some of the characters among treatments. Significant variation in water application efficiency was observed between treatment two (T2) and other treatments at 5% level of significance. The lowest application efficiency (56.17%) was gained from treatment one (T1) and the highest application efficiency (75.87%) was recorded treatment two (T2). Highest water distribution efficiency (90.5%) was also recorded from treatment two (T2) as well as the lowest water distribution efficiency (81%) was from treatment one (T1) as showed in Table 3. The results indicated that water application efficiency and distribution uniformity were highly affected by dimensions of furrow and as well as flow rate. As furrow dimension are managed based on flow rate, water application efficiency and distribution uniformity can be increased. As indicated in Table 3, water application efficiencies showed significant differences among all treatments from which treatment T2 was highest (75.87%) and followed by treatment T3 which amounted 69.44%. But treatment T1 revealed lowest (56.17%) water application efficiency among others due to mismanagement of irrigation water. Significant differences in irrigation water distribution efficiencies were also observed between treatment T1 and the rest treatments at $p \leq 0.05$ which ranged from 81% (T1) to 90.5% (T2). However, no significant variation recorded between treatments T2 and T3. There were significant differences among all treatments in water productivity.

Yield and yield components

Analysis of variance showed that, there were significant differences among the means of plant height and grain yield (Table 3). There were significant differences between treatments T2 and other two treatments in plant height. However no significant variation was recorded between treatments T1 and T3. Plant height ranged from 39.28 to 41.53 cm under T1 and T2 respectively. Significant difference was obtained among all means of treatments under grain yield. The highest grain yield (19520 kg/ha) was gained from T2 when compared with the lowest (15088 kg/ha) observed in T1. This was due to blockage of designed furrow at the end of its length and the required crop water requirement was satisfied. In the end blocked furrow, the water only infiltrates to the crop root zone and runoff is reduced. This increases appropriate utilization of delivered irrigation water such as irrigation efficiencies, water productivity and crop yield. About 13000 to 16000 kg/ha has been produced under local farmers' experience. Similarly, previous research findings reported by Guesh (2015) found a closer result for the same crop. There were no significant differences in percentage of stand count of onion among all treatments as shown in Table 4.

Water productivity

As statistical analysis showed, there were significant differences in productivity among all treatments. As indicated in Table 4 the highest water productivity (5.20 kg/m^3) was resulted from treatment two (T2) and the lowest (3.11 kg/m^3) was obtained from treatment one (T1). Similar result was found by (Kang et al., 2000) on water productivity of furrow irrigation system.

CONCLUSION AND RECOMMENDATIONS

As the study showed, treatment two (T2) revealed

Table 4. Growth parameters, yield and water productivity of onion.

Treatments	Stand count (%)	Plant height (cm)	Grain yield (kg/ha)	Water productivity (kg/m^3)
T1	97.713[a]	39.275[b]	15088[c]	3.11[c]
T2	97.278[a]	41.525[a]	19520[a]	5.20[a]
T3	97.282[a]	39.800[b]	18009[b]	4.36[b]
LSD 0.05	Ns	1.4898	1224.6	0.6126
CV%	1.35	7.14	14.04	8.38

Means with the same letter in a column are not significantly different.

superiority in water application efficiency over other treatments. The highest water distribution efficiencies also recorded in treatment two (T2) as compared to the rest treatments. Moreover treatment two (T2) indicated better advantage in water productivity over other treatments. Yield and growth related parameters of farmer practice were found to be the lowest as compared to treatment two (T2) and treatment three (T3). Generally treatment two (T2); Furrow with top width of 45 cm, bottom width of 20 cm and depth of 12 cm indicated better performance in both efficiencies and water productivity as well as yield and growth related parameters. Hence this dimension is recommended for furrow irrigation applied on clay soil texture like in that of the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Value chain analysis of farm grown *Melia volkensii* (Gurke) timber in the South Eastern Dry lands of Kenya

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This paper analyzes the value chain of *Melia volkensii* timber grown on farms in the South Eastern dry lands of Kenya. The "*filiere*" approach was used to analyze the institutional and the economic dimensions of the chain, while technical dimensions were analyzed using on-farm timber sawing systems. Six main actors; tree farmers, timber merchants, sawyers, timber yard operators, furniture makers, and end consumers were mapped. Transporters, though temporary, played intermediary roles of facilitating the linkages. A variety of combinations determined costs and gains along the chain. Some actors circumvented some links to increase revenue. Quality of trees and sawn timber were key determinants of monetary value transacted along the chain. Inadequate farmers' skills in tree silviculture, valuation and cumbersome procedures in obtaining Government permits were also mentioned as major challenges, while timber sawyers lacked efficient sawing technology, consequently lowering income along the entire value chain. To improve the value chain, there is need to address the identified challenges through enhancing information and technology transfer to the players among other interventions.

Key words: Farm grown timber value chains, *Melia volkensii*, "filiere" approach, chainsaw.

INTRODUCTION

Forestry makes substantial contribution to global, regional and national economies as well as improving household livelihoods (Wit and Van Dam, 2010). In Kenya, forestry is a critical pillar to many sectors of the economy (Wamahiu, 2008; GoK, 2007). Farm forestry plays an important role in supplementing gazette forests in meeting forest products demand (World Agroforestry Centre, 2004; Pasiecznik, 2010). It also helps farmers to diversify income and reduce risks (Roshetko et al., 2008; Muthike et al., 2010). Forest resources assessment in Kenya reported an increase of trees on farm by over 40% between 1990 and 2010 (FAO, 2010). With ever decreasing arable land in high potential areas, dry lands, backed by research and technology, are providing the much needed alternative space for tree growing.

One of the tree species that has been successfully propagated in dry lands is *Melia volkensii*, (Gurke), which is generally referred to as Melia. The species belongs to the Meliaceae family and is native to dry lands of Eastern Africa;Ethiopia, Kenya, Somalia and Tanzania.It grows well in sandy soils with good drainage from sea level to 1700m above sea level and mean annual rainfall of

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between 300-800 mm and temperature range of 26-38°C (KFS, 2018). In Kenya, Melia was successfully introduced and propagated on farms in Tharaka Nithi, Kitui, Makueni and Taita Taveta Counties, which lie in the South Eastern dry lands of the country.

Kibwezi area, which comprises Kibwezi East and West Sub-counties in Makueni County, is one of the areas in the South Eastern Kenya. The area receives a mean annual rainfall of between 300 and 400mm (KFS, 2018). Melia was introduced on farms in Kibwezi in the mid-1990s, alongside other areas in Kitui and Tharaka Nithi counties, following extensive collaborative research between Kenya Forestry Research Institute (KEFRI) and other partners involving technology development for seed treatment to break its characteristic dormancy and propagation of the species on farms. To date, a good number of farmers in Kibwezi have adopted Melia tree farming, with a number having relatively large wood lots under *Melia volkensii* and a few running into plantation sizes. The government has continued to encourage farmers to adopt the species in an effort to bridge the gap in forest cover in line with the Kenya National Forestry Programme 2016-2030 (MENR, 2016) and the aspirations of the Kenya Constitution 2010. Other Non-Governmental organizations have also been helping farmers in other dry land areas to grow Melia trees. A good example is along the seven forks dam belt on the border of Embu and Machakos counties, where over 2000 farmers have each set aside at least 2 acres to grow Melia, with support from Better Globe Forestry (BGF) (Karuga, 2016).

The problem statement

Melia is a fast-growing dry land species, producing high value timber. Though indigenous in drylands like Kibwezi, it is new on farms and its commercial utilization is still in its infancy. Before adaptation on farms, Melia wood from wild trees had been used for building traditional houses, fencing and for tool handles. After introduction on farms in the early 1990s, mature trees are converted to sawn timber for furniture and other new products, opening new trade pathways but at small scale. However, with increase in interest in the species, more business players like timber merchants are beginning to appear, buying trees for conversion to sawn timber, which is sold to other regions (Wekesa et al., 2012). Brokers have similarly tried to find their space, connecting tree farmers and new merchants for a fee. With these increased entrants, the value chain has expanded and prices of the final sawn timber and timber products increase due to the rising transaction costs. This study was therefore designed to map and analyze the Melia timber value chain in Kibwezi area and establish the distribution of benefits along the value chain. The study analyzed the institutional, technical and economic dimensions of the Melia timber value chain and examined the challenges faced by players and possible solutions, all aiming at assisting investors interested in Melia timber to make informed choices on their preferred entry points.

METHODOLOGY

Study area

The study was carried out in Kibwezi (East and West) Sub-counties, Makueni County in the South Eastern dry lands of Kenya. The area bordering the Chulu Game Reserve and both Tsavo East and Tsavo West National Parks is fairly dry, receiving a mean annual rainfall of 300-400 mm per year, in two seasons, October-December and March – May (KFS, 2018). With such low rainfall, only drought resistant tree species can survive in the area. The area was purposefully selected for this study because many farmers have been growing Melia trees from the time of introduction, and trade activities around Melia timber have surfaces though with little organization (Wekesa et al., 2012).

Study approach and data collection

Different approaches have been used in value chain analyses, dictated by the types of chains and their complexities. The *Filiere* approach is one of the widely used methods (Bernstein, 1996). The term *filiere* means a "thread" and refers to a market chain, comprising the stages from the raw material producers to the final product consumers. The approach was developed to analyze price information through a commodity journey from raw material to final product (Freud and Dabat, 2000). It specifically addresses social relations, institutional arrangements and the role of actors in complementing conventional economics. In this study, *Filiere* approach was found appropriate owing to the newness of the product (*Mellia volkensii* timber) and therefore the type of players trying to fit themselves into the value chain.

The study aimed at documenting the various stages of the value chain; major actors; their relationships, costs and revenues involved at each stage (Bernstein, 1996). Tree farmers who participated in the initial establishment of Melia species (now organized into a cooperative) were used to provide information on tree growing and trade. To understand the timber business practices in the study area, a survey was conducted in Kibwezi town and the surrounding major market centres; Makindu, Kinduani/Mbui Nzau, and Mtito Andei, targeting timber yard operators and carpenters as well as transport service providers. This was aimed at providing information on the extent of timber-based businesses, timber species used, major sources, value addition practices and final products made as well as prices. A business census was then conducted to establish the number of sawyers, timber merchants, timber yard operators, and carpenters in the study area. Transport providers and brokers were also included to understand their involvement in Melia timber business.

Analysis of institutional, economic and technical dimensions

Data collection was grouped into three components: institutional, technical and economic dimensions. Institutional dimension involved the relationship between direct and indirect actors and their individual and/or collective objectives. Analysis of the economic dimension interrogated the costs and revenues as a result of operations at each stage of the chain. It also looked at the proportion of the price of final product (sawn timber) amongst the actors along the entire chain, the strong and weak transfer points in relation to prices, cost cutting mechanisms between stages and how players were being affected by changes in the relationships among them. For both institutional and economic dimensions, structured questionnaires were developed according to the theory and principles of the *filiere* approach (Bernstein 1996), as described by Freud and Dabat (2000). The questionnaires were pre-tested to identify the value chain links and the actors in each link, degrees of integration and the types of combinations and options in between. Computation of price transfer between stages was performed based on timber standard volume (board foot), to evaluate the value added and net margins at each stage. Group discussions were conducted separately for each category of players, aimed at determining the challenges they faced in the various links (growing, processing and marketing/utilizing Melia timber products), and their suggested solutions towards improving the value chain.

Technical dimension focused on timber sawing operations, technology used, constraints and how to improve efficiency. Due to lack of formal saw milling practices in the study area, owing to lack of forests, timber was sawn using freehand chain sawing method, which is the common sawing method used by the local timber sawyers. One local experience chainsaw operator was used to saw part of the timber. An improved framed chainsaw system, developed by KEFRI (Muthike, 2016), was used to saw the other part of the timber for comparison of efficiency. The framed chainsaw system was operated by a trained KEFRI chainsaw operator.

Six mature Melia trees of good stem form were selected from the farms and felled using chain saws. Each tree was crosscut into logs depending on market dimensions for sawn timber lengths. Log diameters were measured at the bottom, middle and top of each log. These measurements were used to compute log volumes. Half of the obtained logs were sawn using freehand chain sawing method while the other half was sawn using the framed chain sawing system. All logs were sawn to standard sawn timber dimensions. Log and sawn timber volume and recovery were computed using standard timber conversion methods (ISO, 1983; ISO, 1974). Timber surface roughness was determined using the procedure described by Richter et al. (1995) and Funk et al. (1992).

Data analysis

Data analyses were carried out using Microsoft Excel 2010, SPSS version 17 and Minitab14. Data distribution was determined using Microsoft 2010. To compare differences in the transaction costs and revenues, analysis of variance (ANOVA) was used. Univariate analysis was used to show the variation of revenues along the value chain links.

RESULTS AND DISCUSSION

Melia timber value chain mapping and analysis of institutional factors

The study mapped a multi-staged Melia timber value chain operated by different categories of actors, with varying sets of interactions as shown in Figure 1. The direct actors involved in the value chain include tree farmers, timber merchants, sawyers, timber yard operators, furniture makers and furniture consumers. Farmers grow and sell standing tree to timber merchants and other buyers including neighbours for their domestic use. The merchants hire chainsaw operators to fell and convert the trees to sawn timber. Sawn timber is sold to timber yard operators, who stock and sell the same to furniture makers for further processing into furniture and other timber products for final consumption. Within these activities, transporters are engaged in transporting sawn timber and/or finished furniture products to the designated stages in the value chain. Transporters occasionally provided additional jobs to other people as loaders.

A part from the main actors, other relationships existed, where players circumvented some chain links to cut costs (indicated by dotted lines and/or double arrow). In some cases, brokers come in between and made money by connecting players in a link, which increased the cost of the final product. Brokers for example would be hired for a commission by timber merchants to scout for mature trees. Some brokers would buy trees from farmers and sell them at a profit to merchants, sawyers, timber yard operators or furniture makers. This tends to increase the cost of trees. On the other hand, some timber yard operators bought standing trees from farmers, instead of sawn timber from merchants. Farmers themselves would at times hire sawyers to process the trees into sawn timber. Similarly, some furniture makers reported that when they have special orders that require non-conventional timber dimensions, they approached farmers to buy standing trees. These trees would later be sawn to the carpenter's specified dimensions, which enabled them to circumvent some steps tended and consequently lowering costs by shortening the value chain.

Analysis of economic factors

Results indicated that value addition took place in a variety of forms as the main and subsidiary actors interact at various links of the chain, from the standing trees to the final timber products. For ease of analysis of value addition, the study concentrated only on stages from standing trees to sawn timber. Furniture making was left out due to the additional materials needed like adhesives, varnishes and upholstery among others, which make analysis of the value addition more complex. However, consideration was given to Melia timber playing a more preferred substitute to other timber species initially brought from other regions for making furniture. The distribution of the gains due to value addition along the chain is shown in Table 1.

Other factors that influenced the value transacted at various links of the chain included the quality of the standing tree stems and that of the resultant sawn timber. The buyers sought straight long stems with fewer knots, to get high quality timber. Carpenters with specific orders (e.g. school furniture) would be willing to pay more to select the required timber from yards or select standing trees with suitable stem characteristics and pay a premium price. Thus, farmers got paid more per board foot of sawn timber when they sold trees with good stem form.

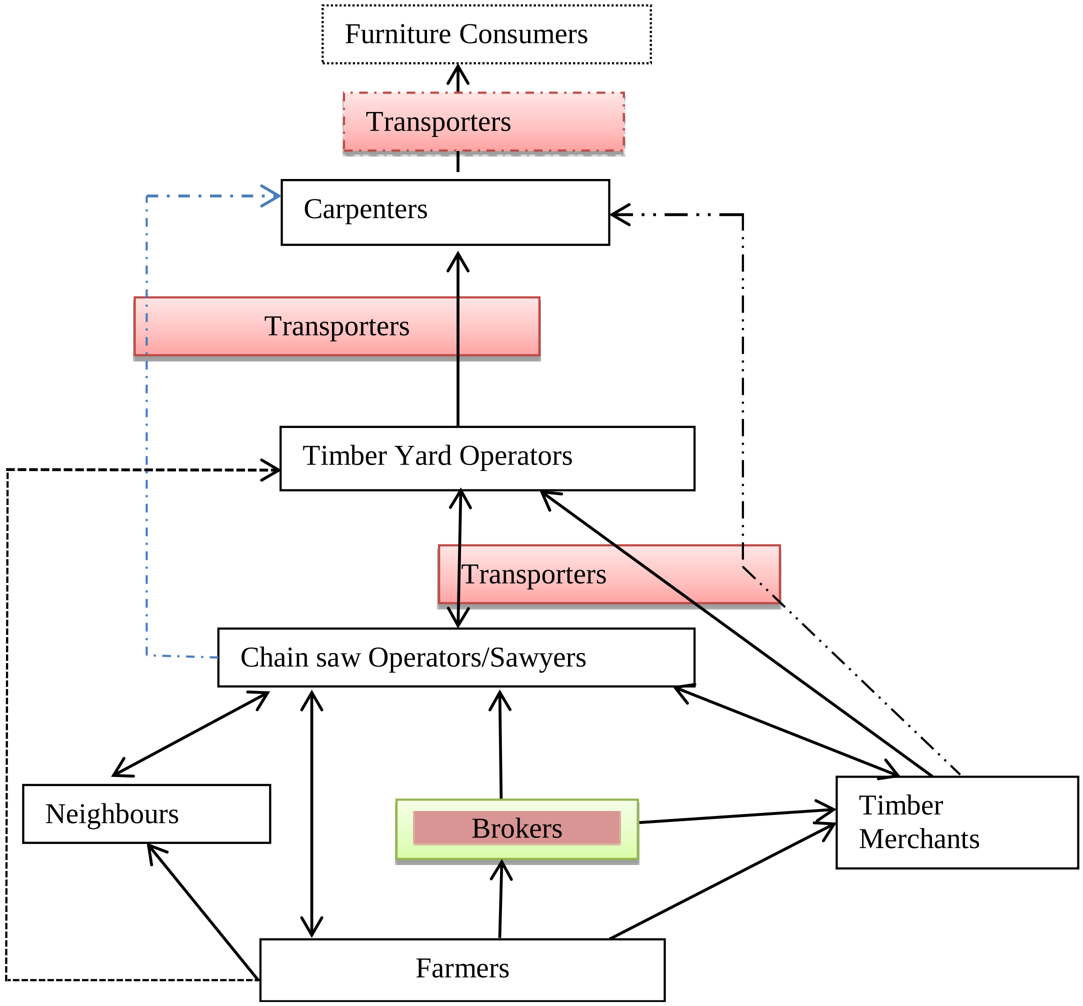

Figure 1. Melia timber value chain in Kibwezi Sub-county, Kenya. The chains indicated in one sided arrow solid lines indicate the most commonly occurring direct structures and stages of the value chain. Double solid lines indicate cases where materials go to and from each actor. Circumventive chains are indicated by dotted lines. Chains that go through transporters are indicated by lines going through Transporters. Other minor players like loaders are covered under transporters. The top two stages (Transporters and Furniture consumers) are indicated in dotted lines because they are not analyzed in this study, whose scope covered up to carpenters as the consumers of Melia sawn timber.

Costs and gains along the value chain were also influenced by players circumventing some stages and engaging in value addition operations themselves. For example, when farmers had the trees converted to sawn timber, there was an additional gain of at least KES 19-29 per board foot, attributed to value addition and sale of offcuts and fuel wood. Similarly, timber yard operators gained an additional KES 12-20 more by buying trees and converting them to sawn timber instead of buying sawn timber from merchants. This gain is additionally attributed to the value of the offcuts, which would add to the sales. Similarly, carpenters realized an additional gain of KES 10-18 when they bought standing trees directly from farmers and hired sawyers to convert the trees to sawn timber. Tree buyers tended to pay higher when they initiated the sale and less when the farmer had to look for them. Brokers were also reported to offer the lowest prices for the standing trees and in such scenario, the farmers neither got full value of their trees nor did they have power over how the trees were processed. This has been reported in other studies as one of the reasons for farmers not finding tree growing on their farms a lucrative activity owing to the length of time it takes to raise a tree to maturity (Wit et al., 2010; Fehr and Pasiecznik, 2006). Because of low volumes of sawn timber and furniture products traded in the study area, there were no designated transport providers. Therefore, players hired transport as and when needed. Major transportation means reported along the value chain was pickups and motor cycles. The cost of transportation for sawn timber

Table 1. Major Actors in Melia timber value chain.

Actor	Number identified in the study area	Mean age (Yrs)	Who they sell to/serve	Gain/BF of sawn timber (KES)	Mean Gain/BF (KES)
Farmers	15	52	Neighbours, merchants, sawyers, brokers, timber yards	18 - 21	19.5
Brokers	6	29	Timber merchants, sawyers,	9 - 13	11
Timber Merchants	4	31	Timber yards, Furniture makers	10 -16	13
Sawyers/chainsaw operators	17	25	Farmers, neighbours, Timber merchants, timber yards, Furniture makers	12 - 15	13.5
Transporters	Various	-	Farmers, neighbours, Timber merchants, timber yards, Furniture makers, consumers	10 - 14	12
Timber Yard operators	8	32	Furniture makers, house builders,	14 - 16	15
Sub-total				**78 - 95**	**86.5**
Furniture makers	21	27	Households, urban dwellers	25 – 53	39
Grand-total				**103 - 148**	**125.5**

1 USD = KES 100 (2018/2019).

Table 2. Timber recovery and quality analysis.

Sawing system	Timber recovery (%)	Dimension deviation (mm)	Surface roughness -Ra (µm)
Freehand chain sawing method	29.4	5.32	162.18 ± 32.57
Framed chain sawing system	48.7	2.48	107.54± 11.81

and furniture products was reduced when large quantities were transported at a time or when motor cycles were used for smaller consignments instead of pickups. Moreover, large trucks were not frequently used in timber business in the study area, as logs are usually sawn on felling site using chain saws.

Analysis of technical factors

Technical factors in this study focused mainly on the efficiency of sawing technologies used, timber dimensions and surface quality. Observations showed lack of formal sawmills and other value addition practices like timber seasoning, grading and preservative treatment. Technical analysis revealed that the freehand chain sawing method currently being used recovered less timber with higher dimensional variability and rougher surface than framed chainsaw system as detailed in Table 2.

Framed chainsaw recovered 48.7% of the logs into sawn timber. This was significantly ($p = 0.031$) higher than 29.4% recovered using freehand chain sawing method. Dimensional variability and surface roughness (R_a) were also significantly lower ($p = 0.001$) at means of 2.48 mm and 107.54±11.81µm, respectively for timber sawn using framed chainsaw system compared to 5.32 and 162.18±32.57 µm in timber sawn using free hand chain sawing method. These results, though slightly different, show some similarities in range with results reported in earlier studies. Guillaume et al. (2010) reported timber recovery rates ranging from 28 to 35%, for freehand chain sawing, using different timber species and stem diameters. Muthike et al. (2013) reported sawn timber recoveries of 48 to 56% for framed chainsaw system. Small variations may be attributed to among other factors, influence of log diameter and stem form as well as sawyer’s experience (Muthike, 2007). The analyses in this study revealed that the technical aspects (timber sawing technology) influenced the profitability along the Melia timber value chain.

Tree buyers tended to offer lower prices for standing trees to compensate for the losses incurred through inefficient freehand chain sawing. Furniture makers and other sawn timber consumers also tended to avoid sawn timber with high dimensional variability and rough surfaces. They offered lower prices because it required more time and higher machining costs to smoothen and obtain even timber dimensions for the various applications. Inefficient sawing therefore contributed to material wastage, and has been repeatedly reported as a major contributor to the depletion of tree population in plantations and farms alike (Muthike et al., 2013; Holding-Anyonge and Roshetko, 2003). Consequently, low income to the farmers serves as a disincentive to planting more trees.

Challenges and possible solutions in Melia timber value chain

Tree farmers, sawyers and furniture makers outlined the challenges they faced. Apart from low prices offered for standing trees, farmers identified lack of tree valuation techniques, cumbersome procedures in obtaining permits from Government when intending to cut trees, and lack of more valuable alternative uses for Melia trees, as some of the other challenges they face. They proposed the following as possible solutions to these challenges; forest experts need to provide guide lines to farmers on tree volume estimation and valuation. Information on tree management particularly spacing and pruning to produce trees for sawn timber was also highlighted as important to farmers. They also pointed the need for the Government to remove the requirement for forest produce movement permits since farmers in the study area have no possibility of interfering with state forests as there is none in their neighborhoods.

Timber sawyers on their part observed that timber sawing as the sole source of income was currently un-sustainable, because only a few farmers have mature trees and some are unwilling to sell or convert into sawn timber. They however were optimistic that with increase in availability of maturing trees, sawyers would be guaranteed of sustainable livelihoods. Other challenges identified include poor stem form for sawn timber production due to poor silvicutural treatment and lack of efficient sawing methods for higher timber recovery. Based on the results of technical analysis, sawyers agree that the freehand sawing method they had been using is inefficient and uneconomical, causing losses to both the tree farmer and the sawyer. They voiced a need for capacity building to adopt the improved framed chainsaw system to increase timber recovery and enhance surface quality as well as operator safety and ergonomics.

Furniture makers on the other hand identified general shortage of Melia timber and poor timber surface as key challenges to their work. They praised the introduction of framed chainsaw system as a possible solution, providing uniformly dimensioned timber with fairly smooth surface. They also suggested that farmers need to increase trees on their farms to increase supply of sawn Melia timber, which has superior mechanical properties for furniture making.

CONCLUSION AND RECOMMENDATIONS

The study highlighted institutional elements of management, economic operations and technical aspects at the various stages of the chain as the key factors influencing the efficiency of the Melia timber value chain. From the purchase of trees at the farm to the sawn timber at the timber yard or furniture workshop, best value was achieved when main players at one stage managed to shorten the chain by trading directly with the next main players. Sawyers and furniture makers gained more through improved efficiency of the timber sawing technology.

The focus group interviews demonstrated farmers' awareness that they were not getting full value of their trees, due to lack of adequate knowledge on tree management and valuation. Further, farmers and sawyers' gains were negatively influenced by inefficiency of the timber sawing technology used by sawyers. This calls for the relevant agencies to promote capacity building of farmers on tree management and chainsaw operators on improving timber recovery and quality.

Further, the study concluded that inefficient timber conversion, lack of other value addition methods lead to waste, exacerbating unsustainable wood supply scenario. There is therefore need to invest in improving wood processing technologies and capacity to diversify into high value products. While efficient conversion of trees into sawn timber instead of selling them standing was proposed as a way to improve the gains by the farmers, it was noted that the superior timber properties of Melia timber could enable it to be processed for higher value products like flooring, which would increase value along the chain.

Most of the businesses along the Melia timber value chain in the study area are small-scale and lack adequate capital for investment. Such businesses were not in a good position to trade in large quantities of round wood or sawn timber. The transactions involved selling a single tree or a few trees at a time. These are perhaps to be viewed as micro to small-scale, compared to transactions in larger and more established operators, with larger quantities along the value chain. The latter is entrepreneurial scale, which can contribute to the long-term livelihoods, employment and economic growth in such rural setups.

This is what needs to be promoted to grow alongside the growing potential fronted by Melia tree farming in dry lands. Timber recoveries and value can be improved through training farmers on silviculture and tree valuation, capacity building of sawyers to adopt efficient sawing systems, and other players along the value chain on efficient value addition at every stage. The need for timber movement permits may need to be reviewed for people trading with dry land farm grown timber since there may not be possibility of interfering with state forests as there are none in the areas producing similar timber products. It is recommended that tree farmers form and/or strengthen associations for better access to technical information on tree silviculture and management, valuation and pricing. To make the Melia players, more farmers need to be encouraged to grow the species and join the associations. With greater knowledge and capital, farmers' associations can organize centralized selling of trees or process the trees into sawn timber for higher value. Further, timber sawyers should be encouraged and facilitated to adopt framed chainsaw and other efficient sawing systems for higher timber recoveries and higher timber surface quality. Further, traders of higher value products like flooring should be encouraged to try the Melia timber due to its superior mechanical properties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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

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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

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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).

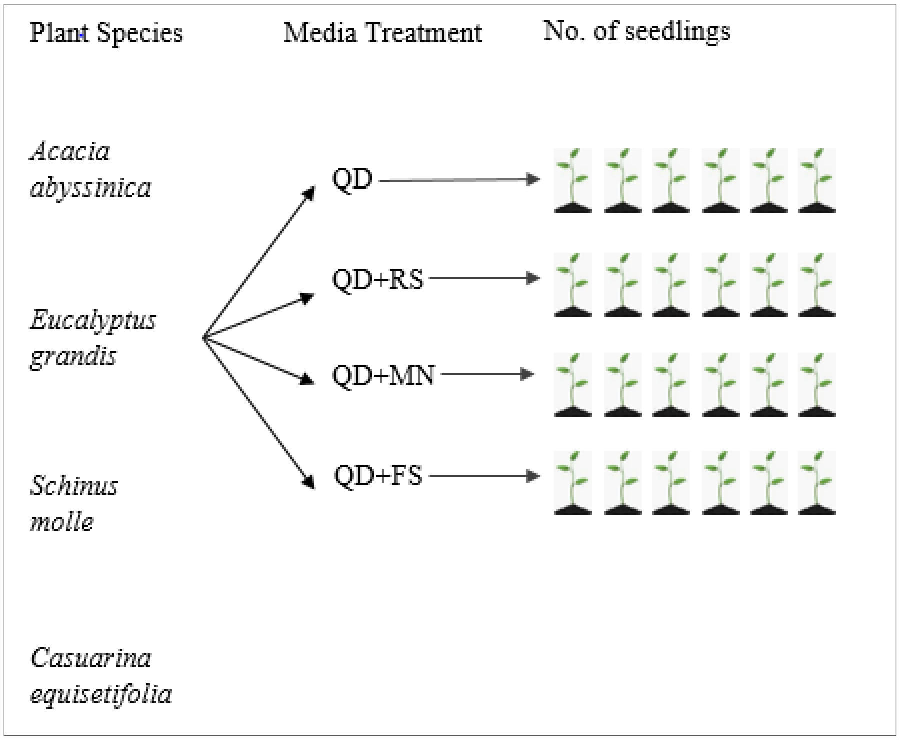

Figure 1. Experimental illustration of the plant species in different media treatments for one replication (QD= Quarry dust, QD+RS= combination of quarry dust with soil, QD+MN= combination of quarry dust with manure, QD+FS= combination of quarry dust with forest soil).

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.

Species	df	Above ground biomass					
		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 6th and 9th 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 6th and 9th 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

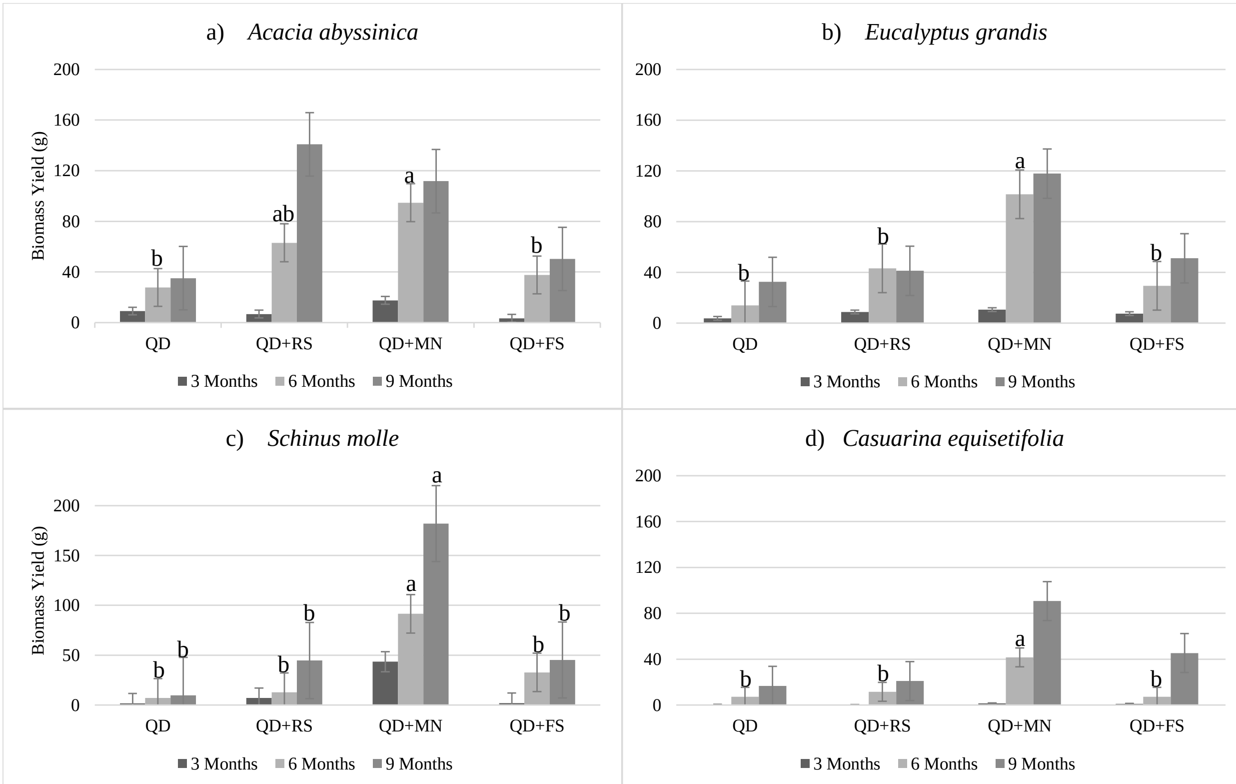

Figure 2. Effects of different media treatments on aboveground biomass for (a) *A. abyssinica* (b) *E. grandis* (c) *S. molle* (d) *C. equisetifolia* plant species in the three different time phases. Vertical bars sharing the same letter in the figure for media treatment in the different months are not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

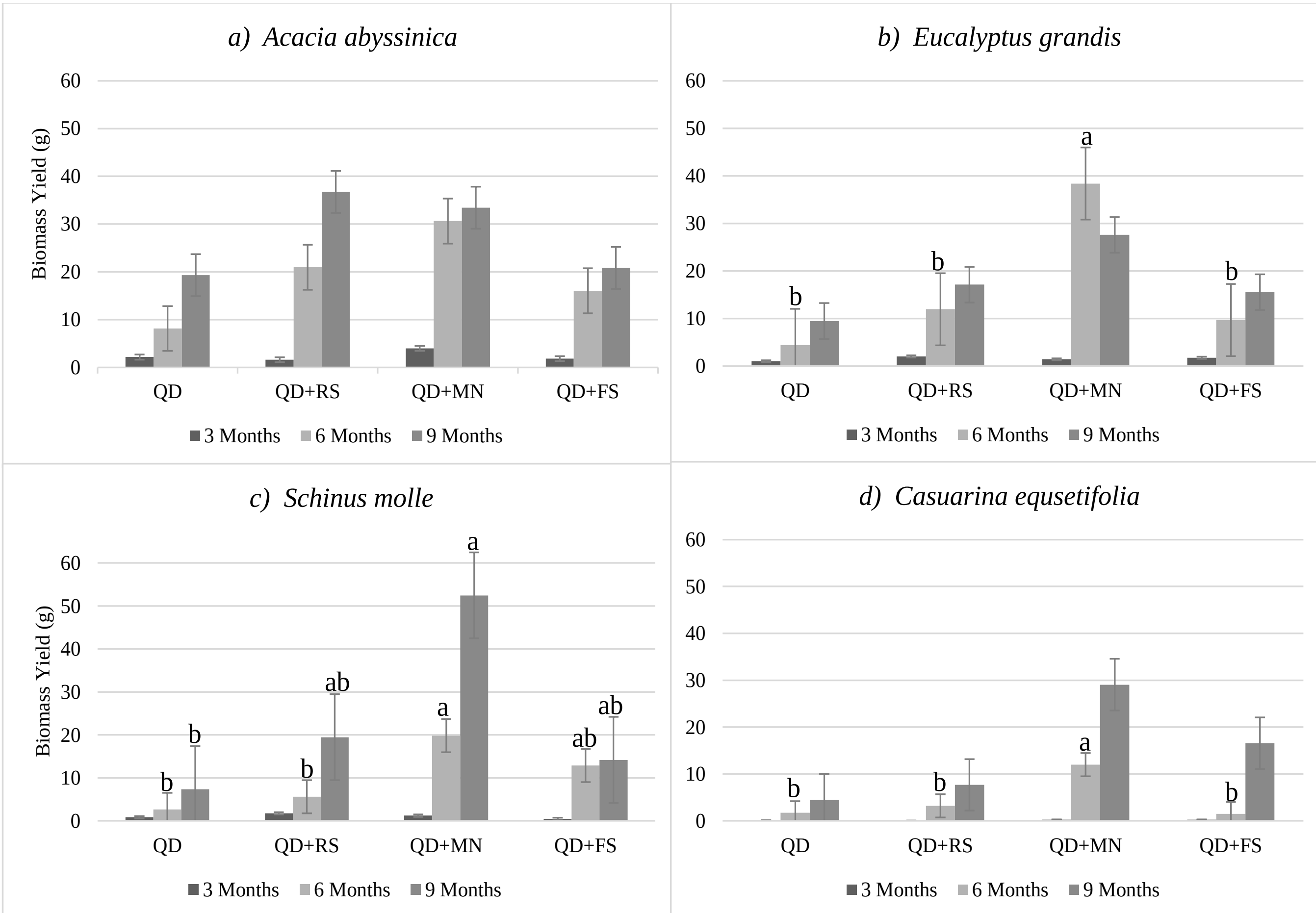

Figure 3. Effects of different media treatments on belowground biomass for (a) *A. abyssinica* (b) *E. grandis* (c) *S. molle* (d) *C. equisetifolia* plant species in the three different time phases. Bars sharing the same letter in the figure for media treatment in the different months are not significantly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

Species	df	Root shoot ratio 3 Months *F*	3 Months *P*-value	6 Months *F*	6 Months *P*-value	9 Months *F*	9 Months *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

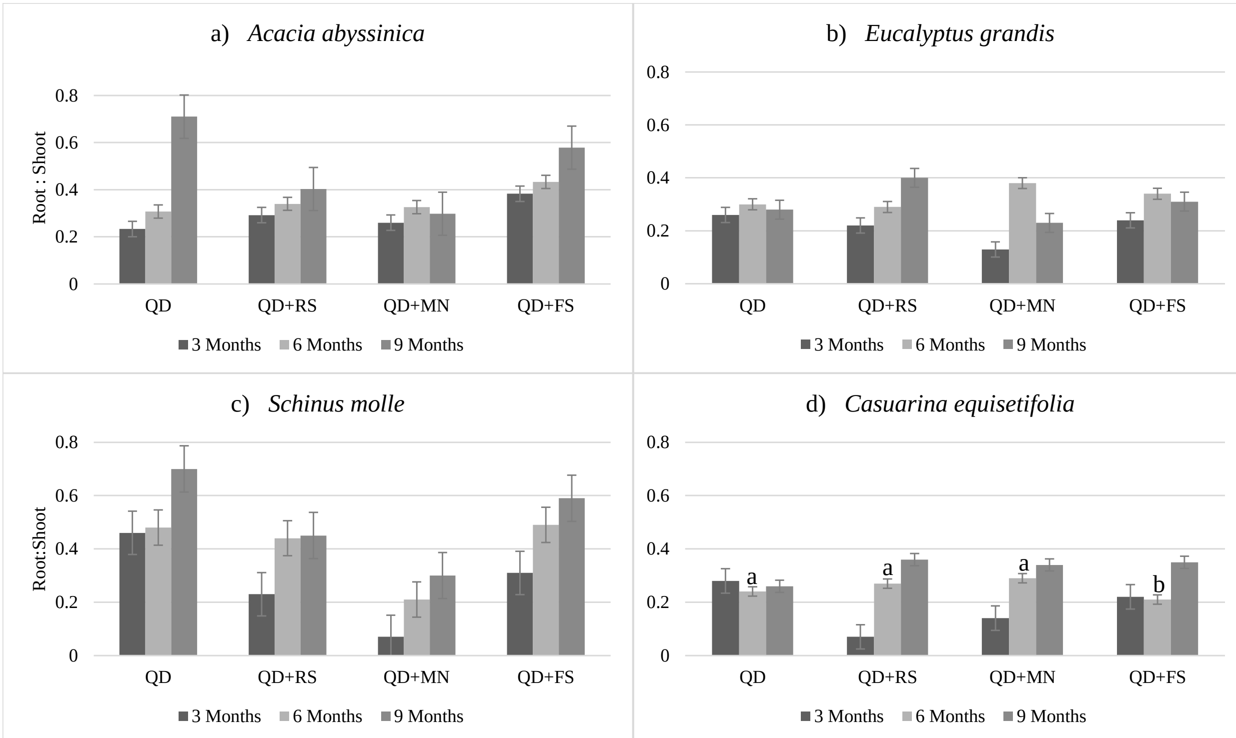

Figure 4. Effects of different media treatments on shoot root ratio for (a) *A. abyssinica* (b) *E. grandis* (c) *S. molle* (d) *C. equisetifolia* plant species in the three different time phases. Bars sharing the same letter in the figure for media treatment in the different months are not significantly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