THE PERFORMANCE OF *Acacia xanthophloea*, *Schinus molle*, *Casuarina equisetifolia* AND *Grevillea robusta* IN THE REHABILITATION OF A LIMESTONE QUARRY AT EAST AFRICAN PORTLAND CEMENT FACTORY, ATHI RIVER, KENYA

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Abstract. Limestone remains the most exploited and crucial industrial mineral worldwide, hence mining activities within limestone quarries will imminently prevail. Quarrying for limestone is an economic necessity that is not only hazardous to humans but also one that invariably has deleterious effect on the environment. Information on the performance of tree species is important as plants are key in the revegetation of exhausted quarries. A comparison of field performance of *Acacia xanthophloea, Schinus molle, Casuarina equisetifolia* and *Grevillea robusta* was made in an exhausted limestone quarry in a semi-arid area, in Athi River, Kenya. The exhausted quarry was backfilled with the mine waste material and then leveled. Four blocks, each 25 m x 25 m, were established at the quarry site for tree planting and control, using the Randomized Complete Block Design (RCBD). Six months old seedlings of each species produced in a nursery were transplanted in the plots. The sequence of planting the four species was varied from block to block. One block was left unplanted for control. Growth performances were estimated by measuring tree height, diameter at the stem base (BD), and diameter at breast height (DBH). Seedling height (cm) and stem diameter (cm) were measured immediately after planting, and thereafter measurements were recorded every two weeks for a period of two years. To avoid border effect, the height and diameter of the middle 10 trees of each species in each block were measured, as these were less susceptible to external influence. The tree height from ground level to tip of the youngest leaf was determined using a tape measure. A Vernier caliper was used to measure basal stem diameter 1 cm above the soil surface. A line was painted on the trunk, to ensure repeat measurements are made at the same point for the diameter. To maintain consistency during data collection, a similar method was used for measurements of diameter at breast height (1m above soil). This commenced at the beginning of year II of planting when most trees had attained a height of at least 1.3 m. Diameter at breast height was measured immediately below a branch if this occurred at a height of 1 m. The study revealed that the time-species interaction was significant ($p<0.001$), indicating continuous tree growth for all the species. The tree species performance was varied. *C. equisetifolia* recorded the highest growth increments for the height (525.3 cm), BD (7.42 cm) and DBH (4.94 cm) and the highest growth rates for tree height (14.24 cm/month), BD (0.23 cm/month) and DBH (0.14 cm/month), indicating superior performance. This was followed by *A. xanthophloea* and *S. molle. Grevillea robusta* showed poor performance and recorded the lowest growth rates: tree height (1.35 cm/month), BD (0.017 cm/month) and DBH (0.023 cm/month). These results also indicated that there is species-specific response that may be due to different water- and nutrient-use strategies and growth patterns. From the study, *C. equisetifolia* has the best growth performance followed by *A. xanthophloea*. The two species are therefore recommended to be used in the rehabilitation of limestone quarries in similar semi-arid conditions.

Key words: Mining, Rehabilitation, Tree Species, limestone quarry

1. INTRODUCTION

Almost all constructions worldwide require cement and concrete, whether they are buildings, bridges or roads. The large demand for cement requires equally large supplies of raw materials, mostly limestone. The limestone comes from calcium rich deposits under the ground and when extracted through opencast mining creates large quarries which are stripped of all their living material and what remains after the extraction is a large sterile quarry that in most cases does not support any life (Chaoji, 2009). The dust from the quarry also covers neighbouring vegetation killing it due to loss of various physiological functions (Osterkamp and Joseph, 2000; Nicolau and Asensio, 2000).

Currently large areas of the study site are completely bare and have a very low natural vegetation cover, consisting of thorny acacia trees. The quarries have sharp drops and the area is covered with huge waste dumps from the mining operations. Like the other major land uses, quarrying is essential to a growing economy, it is conspicuous where it has taken place and unlike other land uses, irreversibly changes the land.

For many years, mining companies focused on ore production and generally neglected the existence of environmental problems (Laurence, 2001). In too many instances, mines have been abandoned in a highly disturbed condition, with limited or no rehabilitation treatment. This can have destructive environmental impacts, and are an unwelcome legacy for governments and communities to deal with (Whitlow, 1991; Nichols and Gardner, 1998; Moffat, 2001).

Rehabilitation programmes have received serious attention in various parts of the world in recent years due to acceleration of mining and associated land disturbance (Toy and Griffith, 2001; Rao and Richa, 2002). Recent awareness of the need to repair the damaged lands has prompted new approaches to quarrying, with the statutory requirement to restore the landscape. Hence, restoration of mine wasteland often requires active human intervention if the restoration goal is expected to achieve rehabilitation within a reasonable timeframe.

The study area is situated in Athi River area, Machakos District, approximately 30 km South-East of Nairobi and is adjacent to the main A109 Nairobi-Mombasa road (Fig. 1).

Rehabilitation of the mine site using the appropriate vegetation will lead to better utilization of resources, improved community health, as the amount of dust will have been reduced, and it will help in the establishment of an ecological environment that will stimulate colonization of wildlife for natural plant propagation, consequently this will increase the biodiversity of the system. Athi River is a semi-arid area with attendant challenges for vegetative growth. The quarry area is therefore largely devoid of any natural vegetation, many years after abandonment. The study therefore aimed at evaluating the performance of several tree species in order to establish a rehabilitation model for the area and others located in similar ecological conditions.

Acacia xanthophloea was chosen for this study because it is native to the study area; it is a leguminous tree and a nitrogen-fixing species (Coe and Beentje, 1991). *Casuarina equisetifolia* is drought tolerant and is host to many microorganisms which fix nitrogen from the air, (Anud, 2008). It has also successfully been used for rehabilitation of the limestone quarries at the Bamburi Portland Cement Company, at the Kenyan Coast (Schoenborn, 2003). *Schinus molle* is fast growing and is an evergreen tree, extremely drought resistant and commonly planted in dry warm climates throughout the world (Iponga *et al.*, 2008). *Grevillea robusta* provides economically viable products and is easy to propagate and establish. Its proteoid roots help it to grow successfully on low fertility soils (Ong *et al.*, 2000).

2. METHODOLOGY

2.1. Propagation and Establishment of Tree Seedlings

Seeds stocks for *A. xanthophloea* were collected from the study area in Athi River and those for *G. robusta, S. molle,* and *C. equisetifolia,* were obtained from the National seed centre, Kenya Forestry Research Institute (KEFRI) at Muguga, Kenya. To initiate germination, all seeds were immersed in water

Fig. 1. Location map of the study area. The Machakos district in Kenya is shown in light purple.

and left overnight, before being planted in trays filled with soil. After three months, seedlings were transplanted into black polythene bags filled with a 1:1 mixture of soil from the quarry site and farm manure. This was done in order to try and simulate as far as possible the soil conditions in the study area (Oballa *et al.*, 1997). The seedlings were grown in a green house established at the study site and watered daily to container capacity. Direct heat and light from the sun were reduced by using a muslin cloth pulled over the green house roof.

2.2. Field Experimental Designs

The exhausted quarry was backfilled with the mine waste material and then leveled. Four blocks A, B, C and D, each 25 m x 25 m, were established at the quarry site for tree planting (A, B, and C) and control (D), using the Randomized Complete Block Design (RCBD).

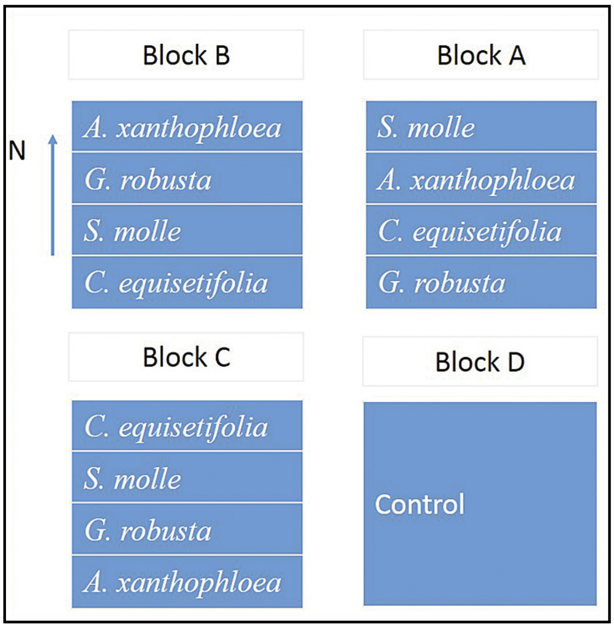

Fig. 2. Experimental Layout for *A. xanthophloea, C. equisetifolia, S. molle* and *G. robusta,* shown within the block design.

Four rows, five meters apart, were then created in blocks A, B and C, and in each row, 20 holes, measuring 40 cm x 40 cm x 40 cm each, were dug one meter apart (Fig. 2). This gave a total of 80 holes per block. These holes were filled with water to bring the surrounding soil to field capacity before planting six month old seedlings of each species in different rows.

The sequence of planting the four species in the rows was varied from block to block. Block D was left unplanted for the control. Fig. 3 illustrates the field layout of the blocks. The trees were planted in an East – West direction to minimize the shading effect (Muthuri, 2004), and were watered twice weekly for the first three months. Trees that died within the first two months were replaced to maintain the correct number of trees per block. Field maintenance procedures included regular hand-weeding around each tree and between the rows. In order to prevent animal access during the establishment stage, the plots were fenced with barbed wire.

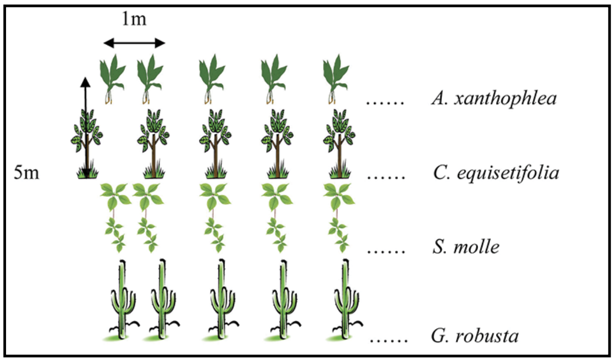

Fig. 3. Experimental Layout for *A. xanthophloea, C. equisetifolia, S. molle and G. robusta,* planted in blocks A, B, and C. Block D was left unplanted for control.

2.3. Growth Analysis

Seedling height (cm) and stem diameter (cm) were measured immediately after planting and subsequent measurements were recorded every two weeks for a period of two years. To avoid border effect, the height and diameter of the middle 10 trees of each species in each block were measured, as these were less susceptible to external influence. The tree height from ground level to tip of the youngest leaf was determined using a tape measure. A Vernier calliper was used to measure basal stem diameter 1 cm above the soil surface. A line was drawn on the trunk, to ensure repeat measurements are made at the same point for the diameter. To maintain consistency during data collection, a similar method was used for measurements of diameter at breast height (1 m above soil). This commenced at the beginning of year 2 of planting, when most trees had attained a height of at least 1.3 m. Diameter at breast height was measured immediately below a branch if this occurred at a height of 1 m (Muthuri, 2004).

2.4. Soil Sampling

After backfilling the quarry, and before the trees were planted, soil samples were randomly collected using an auger within the 0 – 30 cm horizon, to determine the chemical composition and nutrient status of the quarry material.

3. RESULTS AND DISCUSSION

3.1. Chemical Composition and Fertility Status of the Material used to fill the Quarry

It was observed that the soils in the study area (Table 1), had on average, alkaline pH values (8.99) low organic matter content (0.0474%), low total nitrogen (0.005%) and low soil moisture content (0.028%), but soil phosphorus was moderately present (44.15 ppm). The soils also had high to moderate exchangeable bases (Ca, Mg, K and Na), but low manganese and zinc concentrations. The soil values were compared to the Standard of Tropical Soils (Chege, 1982; Lal and Stewart, 1992; Landon, 1991).

Table 1. Soils chemical analysis and nutrient content for soil samples taken within the 0-30 cm horizon, after backfilling the quarry and before planting.

Analysis	Value	Recommended Standard of Tropical Soils (Chege, 1982; Lal and Stewart, 1992; Landon, 1991)	Remark
pH	8.98	6.3-7.5	alkaline
Total Nitrogen (%)	0.005	0.2-0.5	Low
Organic matter	0.047	1.72-3.43	Low
Phosphorus (ppm)	44.15	20-80	Moderate
Calcium (me %)	70.13	2.0-15	High
Magnesium (me %)	8.43	1.0-3.0	High
Sodium (me %)	8.89	0.0-2.0	Moderate
Potassium (me %)	3.66	0.2-1.5	Moderate
Manganese (me %)	1.86	5-9	Low
Iron (ppm)	19.33	>10	Moderate
Zinc (ppm)	4.25	>5	Low
Copper (ppm)	8.06	>1	Moderate
Moisture (%)	0.626		Low

The soils at the study site have similar characteristics to calcareous soils as described by Aguilar (2007). The low soil moisture content is likely to affect any vegetation growth, since soil moisture content is an important property of soils, influencing soil solution chemistry and nutrients uptake by plants (Misra and Tyler, 2000). The presence of carbonates in calcareous soils controls several aspects of nutrient availability (Talibudeen, 1981, Bui *et al.,* 1990). Nutritional and physiological problems in tree growing on calcareous soils may be related to high concentrations of either carbonate or bicarbonate ions (Maynard *et al.,* 1997). High carbonate ion (CO^{2-}) may have an effect on seedling emergence and growth as well as on mycorrhizal development (Lapeyrie and Bruchet, 1986).

3.2. Growth Performance of the Selected Plant Species

Information on the growth patterns for individual tree species is an important tool to determine adaptation in specific environments and systems (Muthuri, 2004), and to determine tree performance. Plant growth was estimated as the increment of the tree height, diameter at the stem base, and diameter at breast height (Clemente *et al.*, 2004), during the study period.

3.3. Tree Height

Casuarina equisetifolia recorded the highest height of 348.8 cm at the end of year 1 of planting (Figure 3), followed by *S. molle* (281.9 cm), then *G. robusta* (214.2 cm) and *A. xanthophloea* (178 cm). However, by the end of the observation period, *C. equisetifolia* gained significant ($p<0.001$) maximum height (525.3 cm) followed by *S. molle* (305.8 cm), *A. xanthophloea* (267.2 cm) and *G. robusta* (231.7 cm). It was also observed that *A. xanthophloea* had the lowest height than all the other species for the first 13 months, after which it became slightly higher than *G. robusta* which recorded the lowest mean height (231.7 m) by the end of the observation period, although the differences between *G. robusta* and *A. xanthophloea* were not significant. Growth rates for tree height was significantly ($p<0.001$) higher for *C. equisetifolia* (17.12 cm/month) at the end of first year of planting (Fig. 4), followed by *S. molle* (9.55 cm/month), *G. robusta* (8.73 cm/month) *and A. xanthophloea* (7.72 cm/month). In year of 2 planting, *C. equisetifolia* again recorded the highest growth rate (11.36 cm/month), followed by *A. xanthophloea* (6.73 cm/month), *S. molle* (1.41 cm/month) and *G. robusta* (1.35 cm/month).

ANOVA (analysis of variance) for tree height revealed that a time-species interaction was significant ($p<0.001$), indicating continuous tree growth for all the species. There was no significant difference in height from the month of May 2006 up to March 2007 for all species, although by the end of year 2 of planting there was significant difference in growth rates between species ($p<0.001$). All the species recorded a lower growth rate in year 2 of planting as compared to year 1 (Fig. 5).

3.4. Basal Stem Diameter

At the end of year 1 of planting, *S. molle* recorded a significantly ($p<0.001$) largest basal stem diameter (BD) (5.95 cm), followed by *C. equisetifolia* (4.92 cm), *G. robusta* (4.09 cm) and *A. xanthophloea* (3.42 cm). However, by the end of the observation period *C. equisetifolia* recorded the largest BD (7.42 cm), followed by *S. molle* (6.23 cm), *A. xanthophloea* (5.35 cm) and *G. robusta* – which recorded the smallest BD of 4.41cm (Fig. 6). Growth rate for BD after year 1 of planting was significantly ($p<0.001$) higher for *C. equisetifolia* (0.329 cm/month), followed by *S. molle* (0.262 cm/month)*, A. xanthophloea* (0.193 cm/month) and *G. robusta* (0.192 cm/month) (Fig. 7). However, by the end of the observation period, *C. equisetifolia* and *A. xanthophloea* recorded significantly ($p<0.001$) higher growth rates (0.137 cm/month and 0.114 cm/month respectively) than *S. molle* (0.021 cm/month) and *G. robusta* (0.017 cm/month).

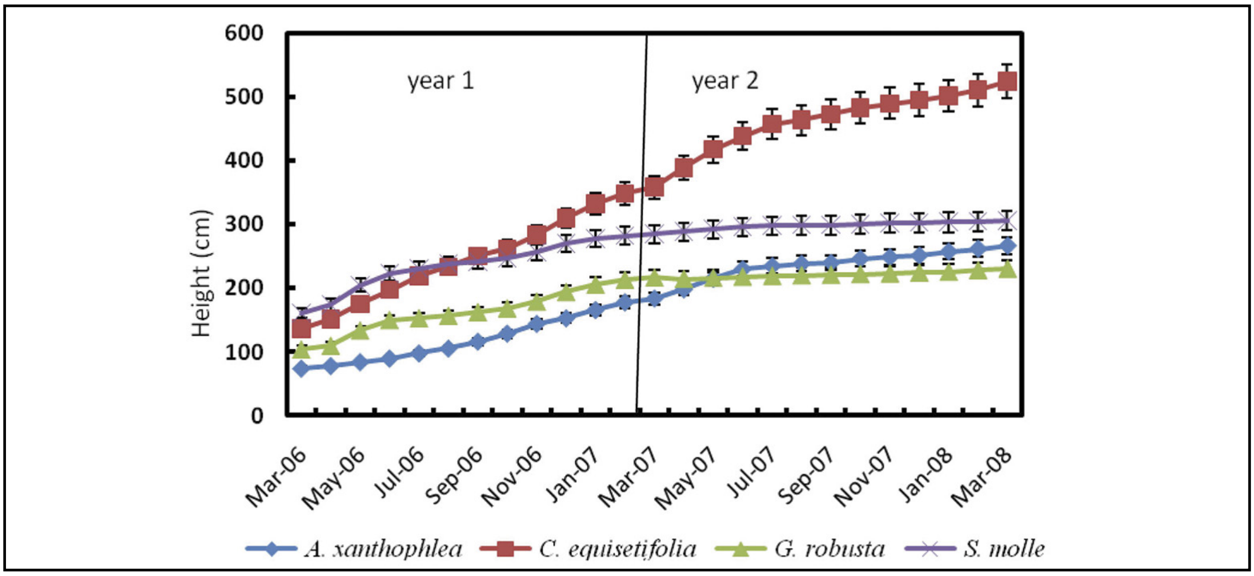

Fig. 4. Time courses of Tree Height for *A. xanthophloea*, *C. equisetifolia, G. robusta* and *S. molle* during the two year period after planting. The vertical bars represent standard error of the mean.

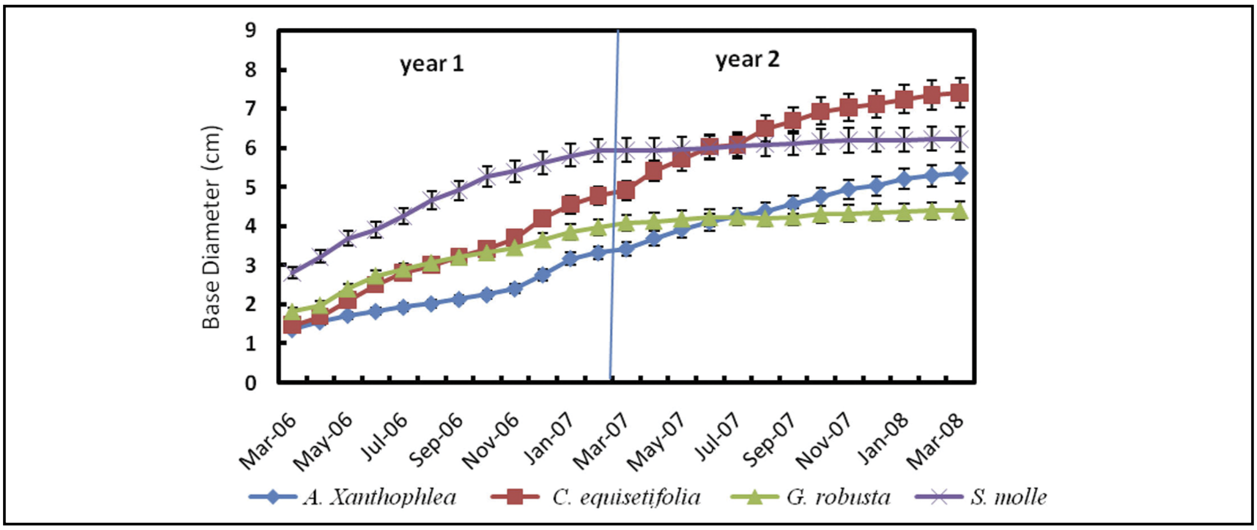

Fig. 5. Growth Rate for *A. xanthophloea*, *C. equisetifolia, G. robusta* and *S. molle* during the two year period after planting. The vertical bars represent standard error of the mean.

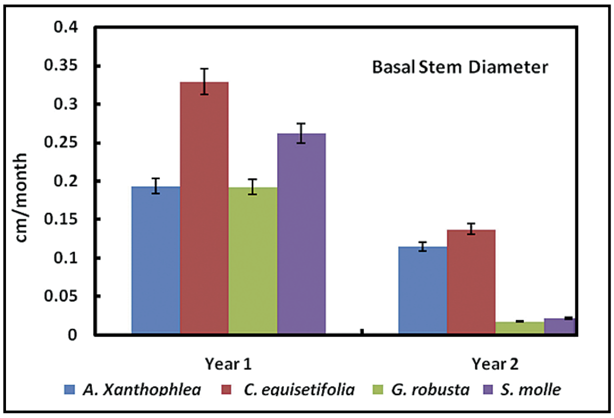

Fig. 6. Timecourses for Basal Stem Diameter for *A. xanthophloea, C. equisetifolia, G. robusta* and *S. molle* during the two year period after planting. The vertical bars represent standard error of the mean.

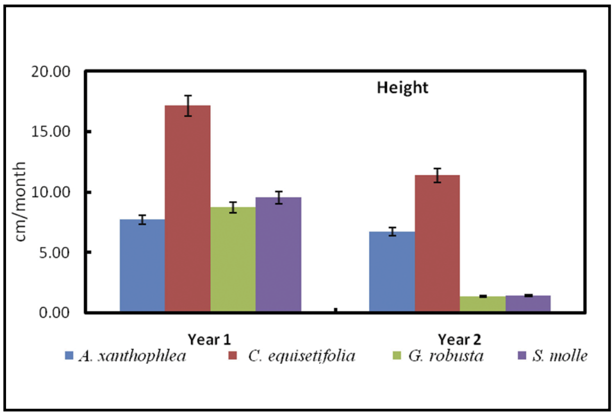

Fig. 7. Growth Rate for *A. xanthophloea, C. equisetifolia, G. robusta* and *S. molle* during the two year period after planting. The vertical bars represent standard error of the mean.

ANOVA showed significant differences between species ($p<0.001$), and between time-species ($p<0.001$), indicating continuous tree growth for all the species. Basal stem diameter was characterized by marked increase during the first year of planting and a reduced rate of increase during the second year for all the tree species. In contrast to tree height, for which substantial species differences were apparent throughout the observation period, the differences in BD were lower and decreased with time. Between June 2007 and August 2007, there were no significant differences in BD, between *C. equisetifolia* and *S. molle* and between *A. xanthophloea* and *G. robusta,* with the species recording almost similar constant values. This was during the dry period which probably had an effect on all the tree species.

3.5. Diameter at Breast Height

Diameter at breast height (DBH), measurements were taken after year 1 of planting (March 2007). This was because DBH was measured 100 cm above ground level, and not all trees had reached a height of 100 cm during year 1 of planting. By the end of the observation period, *C. equisetifolia* had the largest DBH of 4.94 cm (Fig. 8). This was followed by *S. molle* (4.11 cm) and *A. xanthophloea* (2.91 cm). DBH was consistently the lowest in *G. robusta* (2.00 cm). Growth rates for DBH showed significant differences (Fig. 8), with *C. equisetifolia* recording the highest (0.144 cm/month) followed by *A. xanthophloea* (0.086 cm/month), *S. molle* (0.036 cm/month) and *G. robusta* (0.023 cm/month).

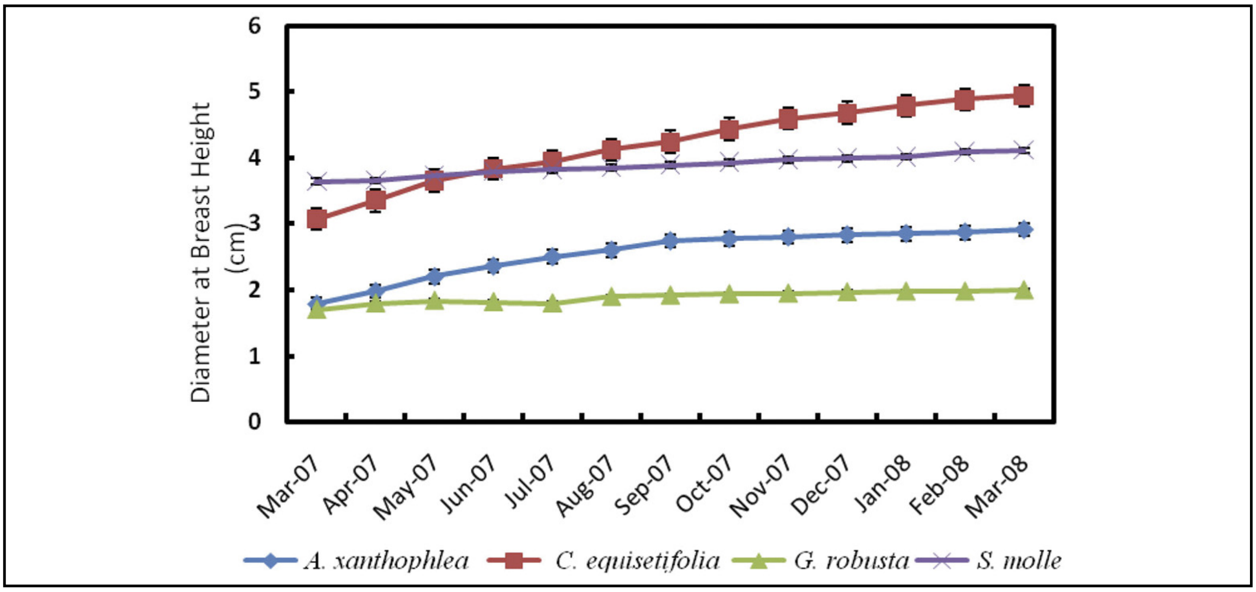

Fig. 8. Time courses for Diameter at Breast Height for *A. xanthophloea, C. equisetifolia, G. robusta* and *S. molle* from May 2007 to May 2008 during the second year of planting. The vertical bars represent standard error of the mean.

ANOVA for diameter at breast height showed that species and time-species interactions were all significant ($p<0.014$ and $p<0.001$ respectively) (Fig. 9).

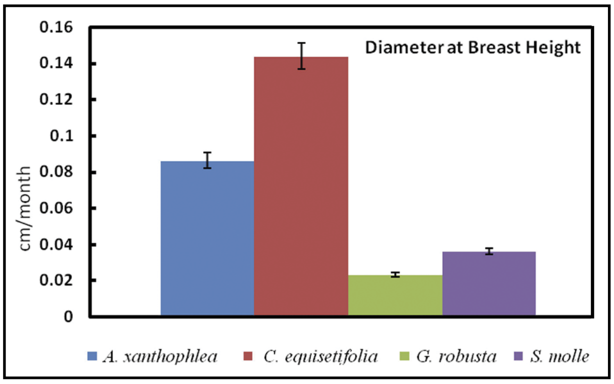

Fig. 9. Growth Rate for *A. xanthophloea, C. equisetifolia, G. robusta* and *S. molle* from May 2007 to May 2008 during the second year of planting. The vertical bars represent standard error of the mean.

All the tree species recorded steady increments for the heights, BD and DBH, throughout the observation period, although smaller increases were recorded in the second year as compared to the first year of planting. The measurements of tree height, basal stem diameter and diameter at breast height showed significant variations for all species. These results indicate that there were species-specific responses during the observation period which may be due to different water and nutrient use strategies as well as species growth patterns (Plates 1, 2, 3 and 4). Within species, differences among plants may have resulted from adjustments in those strategies that are determinant of plant performance under drought conditions.

Casuarina equisetifolia recorded the highest growth increments and mean growth rates for tree height, basal stem diameter and diameter at breast height by the end of the observation period (March 2008), indicating superior performance. This could probably be due to the formation of proteoid, also referred to as 'cluster' roots (sections of the secondary roots which develop as dense cylindrical clusters

Plate 1. *Casuarina equisetifolia* at 24 month after planting

Plate 2. *Acacia xanthophloea* at 24 months after planting

Plate 3. *Schinus molle* at 24 months after planting

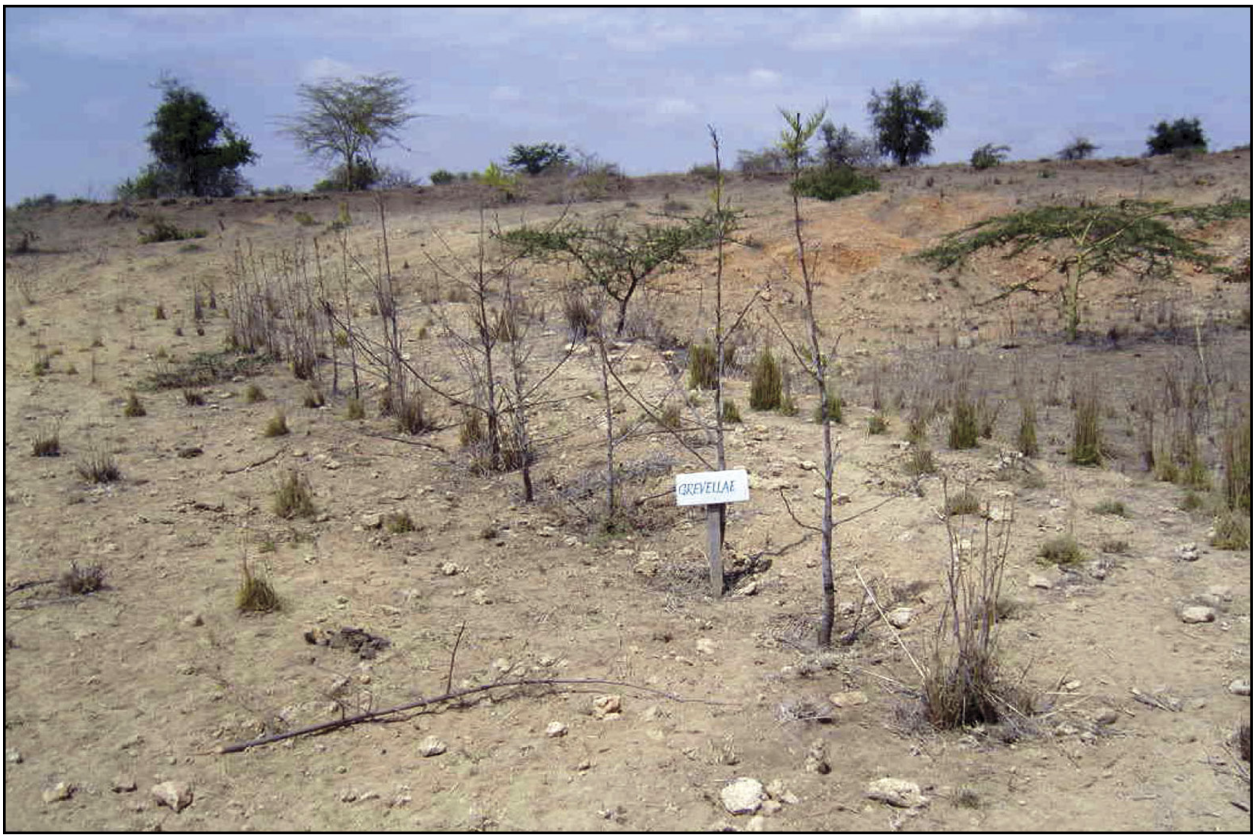

Plate 4. *Grevillea robusta* at 24 months after planting

of rootlets, about 1 cm in diameter) in *C. equisetifolia*. Diem *et al.*, (2000), conducted experiments on an alkaline and an acid soil which showed that *Casuarina* produced cluster roots only in the alkaline soil and this feature is of ecological importance for plants facing nutritional constraints. Results from experiments carried out by Skene (1998, 2000) on three *Casuarina* species (*C. glauca*, *C. cunninghamiana* and *C. equisetifolia*) confirmed that the formation of cluster roots is the consequence of interactions between plants and their environment and in many cases, the influence of a nutritional imbalance is the main cause of this formation.

Grevillea robusta recorded the lowest growth increments and growth rates at the end of the observation period. This may probably be attributed to the fact that the roots could not exploit the upper surface soil horizons for water and nutrients as the tree matured. Skene *et al.,* (1998), reported that *G. robusta* does not form symbiotic associations with soil bacteria or mycorrhizal fungi, although it develops proteoid roots, which are believed to enhance nutrient uptake. Other explanation may be that there were other biophysical limitations at the study site which might include the failure of roots to penetrate the compacted mine floor soils (Hager and Seighardt, 1984). However, at the end of year 1 of planting, *G. robusta* showed higher growth increments for tree height and BD than *A. xanthophloea*. This was probably because seasonal rainfall was higher in year 1 than in year 2 of planting, and therefore water was not limiting and competition for soil water was inconsequential. *G. robusta* also exhibited increased leaf flushing and leaf fall during the study period, which suggests that the process may have been triggered by changing environmental factors such as soil moisture content. Pugnaire *et al.*, (1999), noted that leaf fall appears to be an adaptation to areas subject to water stress. Hence, *G. robusta* generally grew very poorly, devoid of leaves and many were uprooted and toppled by strong winds probably as a result of nutrient deficiency and the failure of roots to penetrate the compacted mine floor soils.

Schinus molle performed relatively well at the end of year 1 of planting and recorded a higher growth increment than *C. equisetifolia* for both basal stem diameter and diameter at breast height. However, in year 2 of plant growth *S. molle* showed growth decline and plant height had almost stagnated (Fig. 4). This may reflect a decrease in soil moisture content resulting from reduced rainfall during this period. The hard below surface rocks probably also disrupted the normal root-distribution pattern, confining root growth to the surface layers of soil. However, further studies are required to confirm this observation.

Although, *A. xanthophloea* recorded the lowest growth increment for tree height and BD at the end of year 1 of planting, it showed a better growth rate than *S. molle* and *G. robusta* and performed relatively well by the end of the observation period. At a mean growth rate of 0.87m/year for *A. xanthophloea*, this compared relatively well with the growth rate of 1.5m/year under ideal conditions (Johnson and Johnson, 1993). *Acacia xanthophloea* has root nodules containing nitrogen fixing bacteria as do most members of the Mimosaceae family and these play an important role in the nitrogen enrichment of soils which then has a positive impact on the growth of plants. *A. xanthophloea* also has a special feature which allows the leaves to close at night and also during extreme heat. According to Passioura (1982), it is the control of leaf area and leaf morphology that is often the most powerful means a plant has for influencing its fate when subjected to long-term water stress in the field. Accompanied by reduced leaf area, plant species that shift growth to the roots are better adapted to survive drought (Osonubi and Davies, 1978). However, this was not assessed in this study.

4. CONCLUSIONS AND RECOMMENDATIONS

From the study findings, *C. equisetifolia* recorded the highest growth increments for height (525.3 cm), BD (7.42 cm) and DBH (4.94 cm) and the highest growth rates for tree height (14.24 cm/month), BD (0.23 cm/month) and DBH (0.14 cm/month), indicating superior performance. This was followed by *A. xanthophloea* and *S. molle*. *Grevillea robusta* showed poor performance and recorded the lowest growth increments for height (231.7 cm), BD (4.41 cm) and BDH (2.0 cm) and growth rate for tree height (5.04 cm/month), BD (0.084 cm/month) and DBH (0.023 cm/month). These results indicate that there is species-specific response that may be due to different water- and nutrient-use strategies and growth patterns.

It is concluded that *Casuarina equisetifolia* can be regarded as a key plant species for plant adaptation related to limestone quarry rehabilitation, due to its superior performance while *Acacia xanthophloea,* that is indigenous to the study area, and has proved to be quite effective, may also be regarded as one of the best tree species for the limestone quarry rehabilitation. Moreover, the fact that *A. xanthophloea* has the ability to enrich the soil through its nitrogen-fixing activity offers an added advantage. Therefore, the present study also concludes that trees should remain an essential feature of quarry rehabilitation in semi-arid environments, due to their role in maintaining the biophysical environment.

Incorporating an increased number of plant species not only provides a greater diversity of products and services, but also beautifies the environment and should therefore be encouraged.

Further long-term studies are also required to determine how the tree species influence on the soil physical and chemical properties observed in the present study change as the trees mature.

A major shortcoming of rehabilitation programmes has been a lack of long-term rehabilitation planning and exit plan. Hence it is recommended that an exit plan should involve a restoration concept at the first point when the feasibility study is started and should encourage the concurrent restoration with mining operation.

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