THE PERFORMANCE OF SELECTED TREE SPECIES IN THE REHABILITATION OF A LIMESTONE QUARRY AT EAST AFRICAN PORTLAND CEMENT COMPANY LAND, ATHI RIVER, KENYA

By

Gladys Gathuru
BSc (Nairobi), MSc (London)
Reg. No. N85/15112/04

A Thesis Submitted in Fulfilment for the Degree of Doctor of Philosophy in Environmental Science of Kenyatta University

March 2011

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

....	....
GLADYS GATHURU	Date
Department of Environmental Sciences	

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

PROF. MWAKIO TOLE
Department of Environmental Sciences
Pwani University College
Kilifi

....	....
Signed	Date

DR. OBIERO ANYANGO
Department of Environmental Sciences
Kenyatta University
Nairobi

....	....
Signed	Date

DEDICATION

This work is affectionately dedicated to my dear husband, Mr. Njoroge Gathuru, for always supporting and encouraging me to complete this study.

ACKNOWLEDGEMENT

I appreciate the multiple assistance I was accorded by individuals and institutions during the period spent to produce this thesis. It is difficult to mention all. First of all, I wish to thank my supervisors; Prof. Mwakio Tole for his continuous guidance and support; Dr. Stephen Anyango, for guiding me throughout this study and the late Prof. Wellington Wamicha for his contribution in the initial development of the research proposal and the field study.

I wish to thank the East African Portland Cement Company Ltd (EAPCC) for allowing me to carry out my study at their quarries and for their initial funding for this study. The members of staff at the Safety, Health and Environment Section of EAPCC were supportive and encouraging during my field study. I am also grateful to Mr. Salem Binale and Mr. Ngeny Biwott formerly of EAPCC for their valuable help in the early stages of my field work.

I also wish to thank the staff at the Mines and Geology Department, Ministry of Environment and Mineral Resources for their assistance with soil analyses. In particular I wish to thank Mr. Lojomon Biwott, former Commissioner of Mines and Geology and also Mr. Joram Wambua, Mr. John Munyau and Ms Juliet Makau of the chemical laboratories.

I sincerely appreciate my colleagues and friends especially; Dr. Esther Kitur and Mrs Catherine Taracha for their valuable comments and constant encouragement to complete the study despite all odds. I doubt if I would finalize this study in the absence of these wonderful people.

I thank my husband, Mr. Njoroge Gathuru and my children, Gathuru and Mugure, for being part of my life and being a dependable source of inspiration and unconditionally supporting, understanding and encouraging me throughout my study. It is exceedingly wonderful to have these people by my side.

I wish to appreciate my father, the late Austin Awori for his love for education.

Finally, I wish to thank Kenyatta University for the Dean's Grant and the six months study leave which also made it possible for me to complete this study on schedule. I am happy to be among the first members of staff to benefit from the Vice Chancellor's project for postgraduate students.

TABLE OF CONTENT

Page

CHAPTER FIVE: CONCLUTIONS AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDIXES

ACRONYMS AND ABBREVIATIONS

ANOVA: Analysis of Variance

APCM: Associated Portland Cement Manufacturer

ASALs: Arid and Semi-Arid Lands

BD: Base Diameter

BPC: British Portland Cement

DBH: Diameter at Breast Height

EAPCC: East African Portland Cement Company

EMCA: Environmental Management and Coordination Act

ICRAF: International Centre for Research in Agroforestry

IUCN: International Union for the Conservation of Nature

KEFRI: Kenya Forestry Research Institute

NEMA: National Environmental Management Authority

RCBD: Randomised Complete Block Design

SPSS: Statistical Package for Social Sciences

ABSTRACT

Quarrying for limestone is an economic necessity that is not only hazardous to human but also one that invariably has deleterious effect on the environment. Information on the performance of trees 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, backfilled with limestone mine waste, in a semi-arid area, in Athi River, Kenya, between 2005 and 2008. The aim of the study was to assess the performance of the above tree species and to determine if these tree species had an influence on the soil physical and chemical properties. The seedlings were produced in a nursery and transplanted in plots established in the exhausted quarry site using randomised complete block design. Growth performances were estimated by measuring; tree height, diameter at the stem base (BD), and diameter at breast height (DBH) from March 2006 to March 2008. The soils physical and chemical parameters measured were: moisture content; organic matter; pH; total Nitrogen; total Phosphorus and exchangeable cations. The study revealed that the time-species interaction was significant ($p<0.001$), indicating continuous tree growth for all the species. The trees 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 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. The soil had low soil moisture content which ranged from 0.67% to 2.3%; alkaline pH, ranging from 8.0 to 8.98; low soil nitrogen content (< 0.03%), related to the limited soil organic-matter content (ranging from 0.05% to 0.38%), and high to moderate exchangeable cations. All the tree species had a noticeable influence on soil chemical properties, by the end of the research period. The pH values and total Phosphorus were relatively lower in soils close to the tree row (0.5 m) and increased with distance from the trees, while the soil values for organic matter, total Nitrogen, and exchangeable cations were relatively higher close to the tree row and decreased with distance from the trees. From the study, *C. equisetifolia* has the best growth performance and also has a higher positive influence on the soil properties followed by *A. xanthophloea*. The two species are therefore recommended to be used in the rehabilitation of limestone quarries in similar semi-arid conditions.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Constructions world wide require cement and concrete. The large demand for cement requires equally large supplies of raw materials, mostly limestone. Limestone comes from calcium rich deposits usually extracted through open cast mining. This 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). However, mankind cannot afford to give up the underground geological resources which are the basic raw materials for development, since an undamaged nature can provide ecological security to people but cannot bring economic prosperity (Sinha, Pandey and Sinha, 2000).

A quarry is a surface mining operated area, which produces enormous quantities of gravel, limestone, and other materials for industrial and construction applications (Duan, *et al.*, 2008). Quarrying is the essential first step in the cement production process because limestone, shale or clay must be extracted from below the ground surface to provide the industry's raw material. Usually where quarrying takes place, the land is cleared of all vegetation, the landscape is drastically altered and the ecosystem totally disrupted (Bradshaw and Chad wick 1980; Roberts *et al.*, 1981; Marrs *et al.*, 1981). Surface hydrology and groundwater levels and flow paths are also altered (Osterkamp and Joseph, 2000; Nicolau and Asensio, 2000). In addition, the common method of quarry exploitation in platforms increases drainage and the physical and chemical erosion of the substrate, hindering natural germination and establishment of young plants, and thus delaying recolonisation. 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.

In Kenya, like other countries, quarrying is mainly for sourcing large supplies of raw materials for the construction industry and other metallic and non-metallic industrial minerals (EAPC, 2009). The rapid and fast construction rates in a pace never witnessed before over the last few years, especially in Nairobi, Kenya has fuelled an ever increasing need for limestone. At the study site limestone is mined in a quarry near Athi River town. The traditional opencast mining practices have caused the destruction of land resources including: denudation of vegetation cover, creation of grossly uneven topography, loss of soil fertility, surface crusting and soil erosion (Sharma and Roy 1997). The dust from the quarry covers neighbouring vegetation killing it due to loss of various physiological functions. This land if inappropriately managed will remain unutilized for centuries. 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.

For many years, mining companies focused on raw material production and generally neglected the effects on the environment of the mining operations (Laurence, 2001). In many cases, 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. In Kenya the Environmental Management and Coordination Act of 1999 (EMCA, 1999), requires good environmental practice even after exploitation of the minerals. This means that after mining, the condition of the land should be restored so that its value is similar to or greater than it was before the disturbance. Although, evidence has indicated that the unassisted process of natural colonization can be very powerful and deliver fully developed and functional ecosystems within 100 years (Prach and Pysek, 2001; Bradshaw, 2000), this does not always occur. The restoration of mine wasteland often therfore requires active human intervention if the restoration goal is expected to achieve rehabilitation within a reasonable timeframe.

1.2 Problem Statement and Study Justification

Quarrying of the limestone deposit at the study site produces huge tonnages of waste material which is dumped at any convenient location. Land around the mines seems too abundant to cause concern. These unconfined disposals of wastes, are major source of pollution to the environment. Substantial research has been conducted on rehabilitation and ecological restoration of mined lands, but most of the research has been focused on large mines where valuable materials including gold, copper and zinc have been extracted. However, little attention has been paid to small quarries which produce low value materials yet all quarries have similar environmental impacts.

Inadequate documentation on mine rehabilitation and of environmental effects of past and present mining at the study area makes the task of understanding and predicting future impacts very difficult. Experimentation has been undertaken at mine sites around the world to attempt to elucidate and overcome limitations on vegetation establishment (Bailey and Gunn, 1991). However, such schemes have only been successful at specific sites, and their widespread application is limited owing to the variation in physical, chemical and biological factors which exist in mine areas (Tordof *et al.*, 2000).

Aesthetic impacts of mining are of critical concern to the rehabilitation specialists. Negative landscape impacts or visual intrusion are greatest with large waste dumps in densely settled areas (Law, 1983). The study area is located 2 kilometres from Athi River town, which has an urban population of

22,000 (Kenya Population Census, 1999), is relatively industrialised, and the town is also a growing residential area due to its proximity to Nairobi capital city. The study area is covered with huge waste dumps from quarrying of the limestone deposit and would therefore have greater impacts on public health. These waste dumps also use up land that could be productively farmed or forested, and the land could also be used for construction of buildings, as is happening across the road from the study site.

Rehabilitation of the mine site using the appropriate vegetation will lead to the EAPCC 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.

Attempts have been made by the East African Portland Cement Company to rehabilitate the quarries through refilling the site with the waste material and planting trees. However, little has been done scientifically to develop specific revegetation approaches for the limestone quarries. The choice of trees in terms of their adaptability, growth and rehabilitation potential of the site needs to be scientifically studied and this is one of the first attempts. Athi River is a semi-arid area with attendant challenges for vegetative growth. The quarry area is largely devoid of any natural vegetation, many years after mining. The study therefore aimed at evaluating the performance of *Acacia xanthophloea*, *Schinus molle, Casuarina equisetifolia* and *Grevillea robusta* tree species in order to establish a rehabilitation model for the area and others located in similar ecological conditions.

1.3 Research Questions

The study sought to answer the following research questions.

1. What is the chemical composition of the mine waste used to back fill the quarry?
2. What is the comparative performance of the planted *Acacia xanthophloea*, *Schinus molle*, *Casuarina equisetifolia* and *Grevillea robusta,* grown in the study area?
3. How do the experimental tree species influence the soil physical and chemical properties over time in the study site?
4. Which is the most suitable tolerant tree species that can be used to rehabilitate Limestone quarries at the East African Portland Cement land, in Athi River and other similar areas?

1.4 Objectives of the Study

The aim of the study was to assess the performance of *Acacia Xanthophloea, Schinus molle, Casuarina equisetifolia* and *Grevillea robusta* tree species grown for the rehabilitation of a limestone quarry to establish the most suitable tree species.

The specific objectives were to:

1. Determine the chemical composition of the mine waste used to backfill the quarry.
2. Determine the comparative performance of the *Acacia xanthophloea*, *Schinus molle*, *Casuarina equisetifolia* and *Grevillea robusta* grown in the study area.
3. Determine the influence of the experimental tree species on the soil physical and chemical properties over time in the study site.
4. Identify the most suitable tolerant tree species that can be used to rehabilitate limestone quarries at the East African Portland Cement land, in Athi River and other similar areas.

1.5 Hypotheses

1. The chemical composition of the mine waste used to backfill the quarry is not suitable for the growth of various tree species.
2. *Acacia xanthophloea*, *Schinus molle*, *Casuarina equisetifolia* and *Grevillea robusta* grown, perform well in the study area.
3. The experimental tree species have no influence on the soil physical and chemical properties.

1.6 Significance of the Study

Inadequate documentation of the geological conditions and the rehabilitation potential of past mining makes the task of understanding and predicting future impacts very difficult. The present study makes an important contribution to an improved understanding of the rehabilitation of limestone quarries in arid and semi-arid areas in Kenya. Such an understanding has provided an opportunity to understand, redesign and improve as well as minimize negative results of surface mining. The study therefore forms a base for developing a rehabilitation plan for the study area. The study generates specific information on the growth performance of *A. xanthophloea, S. molle, C. equisetifolia and G. robusta.* This information will assist in the selection of suitable adaptable tolerant tree species to be used in quarry rehabilitation.

1.7 Scope, Limitation and Assumptions of the Study

The study concentrated only on Athi River, East African Portland limestone quarries located in Eastern Province of Kenya. The study did not undertake all soil aspects of the mined quarry and many other varieties of tree species, owing to logistical constraints.

Measurements were done over a period of three years, though longer periods of time would normally be required to demonstrate changes in soil physical and chemical properties. The study was undertaken on the assumptions that the tree species selected were conducive for rehabilitation of the quarry site.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Previous studies related to the study are review in this chapter under different sections. It outlines cement production in Kenya, environmental problems associated with limestone quarrying and the benefits of quarry rehabilitation. It also presents information on the selected plant species for rehabilitation of the limestone quarry Site.

2.2 Mining and the Environment

Developing countries are often faced with challenges of an exploding population, extensive pollution, rampant poverty, obsolete technology and resource scarcity (Sinha, Pandey and Sinha, 2000). In such countries the sustenance and the survival of the large population assumes high priority, and the environment becomes secondary. The extensive exploitation and utilization of resources without regard to ecology further accelerates environmental destruction mainly through deforestation, soil erosion, desertification, wasteland formation, pollution and acid rains, all in a chain reaction ultimately resulting in degradation of the very resource base upon which the economy of a nation depends. Geological resources are non-renewable resources and hence once mined, they cannot be replaced (Sinha, Pandey and Sinha, 2000). Scientific mining operations accompanied by ecological restoration and regeneration of mined wastelands and judicious use of geological resources, with search for eco-friendly substitutes and alternatives must provide the answer (Hal1, 1980; Thompson *et al*., 2007). Increasing globalisation of the mining industry has led to changing public attitudes regarding the costs and benefits of mineral extraction and an increase in public pressure to minimise the environmental and social costs associated with mineral development. Thus the current study seeks appropriate rehabilitation alternatives of quarries.

2.3 Overview of Mining in Kenya

Mineral resources are an important component of Kenya's economy and have the potential to make a substantial contribution to sustainable economic growth and development. Mineral commodities contribute about 1% of Kenya's GDP. Presently, there are about five major mining companies, ten prospecting companies and over 150 prospectors and miners undertaking various mining activities (McCready, 2007). The Kenyan mining industry is dominated by the production of nonmetallic minerals. These are mainly: soda ash (trona), fluorspar, diatomite, vermiculite, natural carbon dioxide, kaolin, barytes, a variety of gemstones, limestone and lime products including various construction materials.

The cement and construction industries utilize the bulk of the limestone mined and quarried in Kenya. The three cement factories operating in the country, Bamburi, East Africa Portland and Athi River, produce over 2.3 million tonnes of cement to meet local needs and export demands (McCready, 2007). Bamburi Portland Cement Co Ltd exploits coral limestone along the Coastal

Belt. The East Africa Portland Cement Company - the second largest cement producer in Kenya after Bamburi, obtains its raw material from three areas: The Kibini Hill Limestone deposit, which is 110 kilometres from Athi River works, the Oleleshua Hill Limestone deposit, which lies 96 kilometres south of Athi River works in the Namanga – Bissel area and the Kunkur Limestone deposits in Athi River area (the study area), located only 8 kilometres from the EAPCC Factory (APCM, 1977). However, the domestic cement manufacturing industry is going through a tumultuous phase. While it is battling profitability woes on one hand, it also has to contend with increasing levels of environmental activism that is keenly scrutinizing its various actions and their impacts on the environment and society. A recent concern over cement production is the emission of carbon dioxide, the major green gas responsible for climate change.

2.4 Cement Production in Kenya

The Kenyan cement market is showing strong growth, with official statistics indicating that cement production in Kenya increased by 15.5 per cent from 2.8 million tonnes in 2008 to 3.3 million tonnes in 2009 (Omondi, 2010).

In 1955 cement made entirely from local material began to be produced by the British Standard Portland Cement Co. Ltd. (now known as Bamburi Portland Cement Co. Ltd.) at a factory a few kilometers north of Mombasa, Kenya. The cement materials, which consisted of Pleistocene coral limestone, Jurassic shale and gypsum, were calcined in vertical and rotary kilns (Sasson, 1996). In

1958 a second factory, owned by the East African Portland Co. Ltd., began production at Athi River, near Nairobi. A rotary oil-fired kiln was used to produce cement from an unusually low magnesia crystalline limestone quarried near Sultan Hamud, as well as some Kunkur limestone (the study area) from the factory vicinity (APCM, 1977). In 1968 production exceeded 105,000 tonnes (Sasson, 1996). Currently, the Company's expansion effort, complemented by a new clinker plant increased the firm's cement output from 600,000 tonnes to about 1.3 million tonnes per year (EAPC, 2009).

Kunkur limestone quarried at Athi River is a variable superficial secondary limestone, a few metres in thickness and consists of medium and low-grade nodular material locally overlain by up to one metre of hard high-grade caprock. Physically, kunkur limestone is whitish – brown in colour, of medium hardness and occurs as hard, nodular particles of variable sizes. It forms 30% - 40% of the primary raw materials for the manufacture of cement at the Athi River Cement works, the rest being crystalline limestone mined from Kibini Hill and Bissel in Kajiado District (APCM, 1977). The first Kunkur limestone investigations were conducted by F.L. Smith & Co. Ltd. in 1954, and a consultant, J.E.P Halse, in 1969. The in-situ Kunkur limestone reserves within the East African Portland Cement Company lease were estimated by the former to be 4.0 million tonnes (APCM, 1977).

2.5 Environmental Problems Associated with Limestone Quarrying

The direct negative effects of mining activities can be an unsightly landscape, loss of cultivated land, loss of forest and pasture land, and the overall loss of production. The indirect effects can be multiple, such as soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity, and ultimately loss of economic wealth (Wong, 2003; Xia and Cai, 2002).

2.5.1 Environmental Impact of Quarrying

Dust from quarry sites is a major source of air pollution: activities like drilling, blasting, material handling and transport are a potential source of air pollution (Sinha and Banerjee, 1994). The main causes of air pollution at the study site are suspended particulate matter, which results from drilling and blasting during rock breaking, the loading and movement of dumper trucks on haul routes, ore processing (since there is a need for crushing the limestone into small sizes) and the bare surface of the waste material generates dust due to wind erosion. When blasting 200–300 tonnes of explosive the volume of dust reaches 20–25 million m^3 (Kashkovsky and Korniolova, 1989; Sinha and Banerjee, 1994). Air pollution is not only a nuisance in terms of deposition on surfaces and possible effects on health, in particular, for those with respiratory problems (Pope, 2004), but dust can also have physical effects on the surrounding plants, such as blocking and damaging their internal structures and abrasion of leaves and cuticles, as well as chemical effects which may affect long-term survival (Vardaka *et al*., 1995). Measurements of < PM2.5 are monitored in recently established mining operations in some countries but are not monitored for abandoned mine tailings disposal sites despite a link to respiratory health problems and the proximity of disposal sites to human populations.

One of the biggest negative impacts of quarrying on the environment is the damage to biodiversity (Kumar *et al*., 1998). Biodiversity essentially refers to the range of living organisms, including fish, insects, invertebrates, reptiles, birds, mammals, plants, fungi and even micro-organisms. During the process of mining, topsoil is stripped off and stored in stockpiles until the mine spoil is ready for reclamation. Storage periods are varied, ranging from less than a year to more than 12 years (Johnson *et al*., 1991; Stark and Redente, 1987). The process affects the physical and chemical properties of the soil. Several researchers have shown that stockpiling also has adverse effects on biological properties. The decrease in microbial activity and mycorrhizal infection potential of stockpiled soil are common (Stark and Redente, 1987). The number of bacteria, fungi, actinomycetes, and algae are reduced in the stored soil when compared to undisturbed soil (Miller and Cameron, 1976). The surface layers are stripped off when mining, therefore most vegetation present is destroyed. This reduces the usable source of carbon available. The carbon biomass of stockpiled soils has been found to be significantly lower than in normal soils (Abdul and McRae, 1984). Loss of organic carbon at the top of stockpiled soils and tough environmental exposure to heat, drying, and freezing-thawing can lead to reduced nutrient cycling and lower availability of nutrients, having adverse effects on the establishment and production of plants when revegetating (Stark and Redente, 1987).

In Kenya quarrying in towns started during the colonial government. The present area of Mathare slums in Nairobi was once a quarry (Osumo, 2001). Quarries are supposed to be isolated from development mainly because explosives are occasionally used to blast rocks. Explosives produce vibrations, noise, chemical fumes, ground tremor and flying rocks. Ground vibrations cause serious cracks in structures making them unstable, while fly-rock and air blast are a threat to life (Osumo, 2001). In 1998, the City Council in conjunction with the Kenya Forest Service, licensed quarrying in Ololua forest in Karen area in Nairobi. The residents commissioned an environmental study that proved that the mining was affecting their nearby homes and lives in addition to the destruction of the unique forest in the city. The quarrying was stopped, though rehabilitation of the already affected land has not been accomplished.

Aspects of mining with a serious visual impact include excavations, waste dumps, refining facilities and increased linear disturbances, such as roads and pipelines. Many parts of the world today remain marred with the unsightly symbols of the continuing quest for the minerals. However, while quarries can cause significant impact to the environment, with the effective planning and management, many of the negative effects can be minimised or controlled and in many cases, there is great opportunity to protect and enhance the environment or the creation of new ones, thus the need for the present study.

2.5.2 Socioeconomic Impacts of Quarrying

Mining activities are most likely to affect population patterns, personality, social and cultural systems. Boom towns have been associated with mining throughout human history, and social disruption has been gradually accepted as one of the costs of economic and industrial growth (Andrews and Bauder, 1968; Little, 1977; Dunlap and Catton, 1978; Busuyi, Frederick, and Fatai, 2008). There is no doubt that mineral exploitation if properly coordinated can have a positive socioeconomic impact on the people of the producing area through the development of some socioeconomic infrastructure such as roads, schools, hospitals, and housing. These may trigger the rise of a wide range of small businesses and the local community can benefit from an enhanced quality of life. At the study site the East African Portland Cement Company has initiated several community projects. These include; One billion tree campaign, community water harvesting and provision, construction of Kasoito slum footbridge and improving the academic life and standards of the surrounding community. With many people directly dependent upon the Kenyan quarrying industry for their livelihoods, employment provision is among the most tangible and important of the potential positive local economic effects of quarrying.

However, despite these benefits, quarrying can also have a number of adverse Socio-economic impacts on the neighbouring community. Losses of agricultural production and freedom of movement, forced resettlement or relocation and a fundamental disrespect to traditions of the local community among others were observed by Hilson (2002), as part of the negative impacts. A recent Kenyan example is the Tiomin Kwale mining project (Canadian investor). The proposed Tiomin mine sites are in a fragile ecosystem in Kenya's coastal forest, which is listed as one of the world's 25 hotspots by Conservation International (Boocock, 2002). This project is highly controversial, from an environmental and socioeconomic perspective (Mugo, 2002). If such projects are to proceed there is need to design an effective rehabilitation plan after the mining programme.

2.5.3 Quarry Accidents and Deaths

In Columbia, 100 gemstone miners were killed by mudslide in 1998 (Masiku, 2008) and in February 2010, 15 workers died when a mound of earth collapsed on them at a quarry in Jajpur district of Eastern India and also 20 workers were feared killed in a quarry in Andhra Pradesh's Prakasam district in India. The 20 people were working 60 to 80 feet deep in the quarry when the landslide occurred (Aggregate Research, 2010). Quarry rockfall in Guangxi quarry in China, occurred without warning in the unrehabilitated quarry and the volume of the landslide was reported to be 21,000 cubic metres. It buried 300 m of road, 16 buildings and five people were killed (Smith and Petley, 2009). Every year about 30 people die in accidents that occur in abandoned or inactive mines, across the United States (Geology, 2005-2010). Drowning is the number one cause of death and in most cases the drowning of children who enter quarries without supervision by adults.

In Kenya many people toil in quarries to make a living, but the sector, perceived as a source of livelihood for many communities, has turned into a death trap. In February 2010, four people were confirmed dead along with one missing after they were buried by rubbles in a quarry near Mukangu village, in Kenya. The Kenya government has since ordered all the quarries in the area closed for environmental audit and those quarries found to be precarious and dangerous to human life would be condemned and closed indefinitely (Mwangi, 2010). Most of the abandoned and unfilled quarries and trenches of varying sizes and depths may act as water reservoirs during the rainy seasons, which may become dangerous for human and animal population. They may also become breeding areas for harmful insects such as mosquitoes and micro-organisms. Several quarries are in close proximity to homesteads, schools, roads, rivers, railway lines and shopping centres, and there are complaints of a nuisance and danger posed by uncontrolled and illegal blasting, dust and water in the pits and also deposition of waste in some waterways (Osumo, 2001). There is notable land degradation in Kenya, due to inadequate rehabilitation and lack of quarries after-use plans (Mwangi, 2010).

2.5.4 Mining and Land Use Conflicts in Kenya

Mining effects are long lasting and in some cases will affect the land use irreversibly. In this context mining activities will always portend conflicts with other land users (Kariuki, 2001). Once the mining is completed, the land may be restored for the previous use or other new uses are introduced. However, in many cases in this country, the quarry sites are abandoned without rehabilitation. This issue breeds conflicts between miners and other land users and environmentalists.

Some of the mineral ores in Kenya are found in the National Parks especially in the Tsavo National Park where the Mozambique belt rock underlies. The Mozambique belt associated with basic and granitic rocks is well endowed with precious minerals and other minerals (Davies, 1993). The conflict is brought about by the two government departments, one the Mines and Geology Department that licenses prospectors and miners on one hand and the Kenya Wildlife Service Department that manages the National Parks and claims the Parks are protected areas and that no prospecting or mining should be permitted (Mathu and Davies 1996). This scenario resembles the current study site where it is generally recognized by ecologists to be a corridor for wildlife migration and this function has therefore been interfered with by the quarrying of the limestone deposit. This demands that the waste lands generated by the mining activities need to be reclaimed such that they may continue providing the ecological services and promote wildlife conservation.

It should also be observed that in Kenya, many abandoned open quarry mines become official waste dump sites in almost all towns, including the Dandora Dump site in Nairobi which is the biggest dumping site in Kenya. Another more resent example is an abandoned quarry in Nairobi's Kayole area where the dumping of waste started in 2009. This may be attributed to the fact that for a long time quarried land was mainly considered as "waste land" and rarely did such operations have a rehabilitation plan. When utilised for dumping such sites develop into a major human health and environmental problem resulting into: Air pollution (a putrid stench permanently hangs in the air), as well as surface and ground water pollution associated with the leachates from such sites (Aluanga, 2010). Ideally such quarries should be rehabilitated upon termination of quarrying to provide an environmentally acceptable and alternative land use.

2.6 Vegetation in Arid and Semi-arid Lands

In East Africa, areas that receive erratic and inadequate rainfall are usually associated with sparse tree growth and are classified as arid and semi-arid lands (ASALs). In Kenya, ASALs constitute about 80% of the total land area (IUCN/ODA, 1995). Water is the single most important limiting factor in these arid ecosystems, hindering growth, development and survival of plants (Kramer, 1980). In the last 70 years, most trials on selection of trees for arid and semi-arid lands in Kenya have been on exotic species which are fast-growing (Millimo, 1989; Oballa *et al.*, 1997). Indigenous species have been neglected because of their slow growth. However past work has also shown that fast-growing species are much more susceptible to drought than slow-growing species (Lediges, 1974).

Members of the genus Acacia form a significant proportion of the indigenous species in Kenya. They are quite distinct in the woody vegetation and cover large areas, either in pure stands or mixed with other shrubs and trees (Akech, 1987). The multiple use value and relative drought resistance of members of the genus Acacia makes it an important resource in these marginal lands. Although, some trees have been found to grow in arid regions, it is not clear yet whether their occurrence in such environments, is due to the existing high water table or because they have some sort of drought tolerance mechanism.

In the past, arid and semi-arid lands in Kenya have been regarded as wastelands. However, there is now a considerable interest in such marginal tropical drylands and efforts are being made for their rehabilitation. Although this has been initiated with the planting of trees, climate and edaphic factors prevailing in such environments have challenged the process (Otieno, *et al.*, 2001).

2.7 Quarry Rehabilitation

In terminology, currently there is no agreed term in restoration ecology with reclamation, restoration, rehabilitation and replacement in synonymous use. Within the mining context, reclamation often refers to the general process whereby the mined wasteland is returned to some forms of beneficial use

(Cooke and Johnson, 2002); restoration refers to reinstatement of the pre-mining ecosystem in all its structural and functional aspects; rehabilitation means the progression towards the reinstatement of the original ecosystem; and replacement is the creation of an alternative ecosystem to the original (Bradshaw, 1990). In previous literatures (between late 1970s and mid- 1990s) almost only reclamation appeared, but after that restoration was more frequently used with occasionally the word rehabilitation used in the accompanying English abstract. In this study, restoration, reclamation and rehabilitation are not distinguished with these definitions and are used interchangeably.

Rehabilitation of mine site in Kenya began in 1970 but has been practiced more widely since the promulgation of the Environmental Management and Coordination Act, 1999. Although restoration is legally bound with the mining activities, the overall restoration rate (the ratio of reclaimed land area to total degraded land area) is very low due to the limited research/studies on land reclamation locally as well as weak enforcement of the relevant laws and regulations. Rehabilitation of wastelands should received considerable attention, since in recent years there has been an acceleration of mining and associated land disturbance (Rao and Richa, 2002). Consequently, lower grade ores are becoming more economically attractive, but exploitation of such ores generates increasingly large amounts of “waste lands” that needs restoration.

During ecosystem redevelopment the initial processes are related to soil development. According to Bradshaw and Chadwick (1980) mine dumps are a stressful environment for plants; this is evident in such environs as they are characterized with sparse, patchy cover and stunted growth as seen in the study area. This is because mine wastes contain no organic matter or macronutrients, (Johnson and Bradshaw 1977; Roberts *et al.,* 1981; Marrs *et al.,* 1981; Krzaklewski and Pietrzykowski 2002). For these reasons, mine wastes remain without normal soil structure and support a severely stressed heterotrophic microbial community (Southam and Beveridge 1992; Mendez *et al.,* 2007). Hence, the microbial community is extremely low in species richness and carbon utilization diversity (Moynahan *et al.,* 2002). These problems may be compounded by climatic conditions especially in arid and semiarid regions. Plant establishment is further impeded by a number of physicochemical factors including extreme temperatures, low precipitation, and high winds (Munshower, 1994).

There are many examples in which mined land has been effectively rehabilitated to agriculture, forestry, nature conservation or urban or industrial land uses (Laurence, 2001). In some of these instances the pre-mining land use was restored, while in others the land use was changed. Some of the changed land uses were carefully planned and implemented, while others have evolved, sometimes after the land has undergone a lengthy period as abandoned or waste land (Moffat, 2001). Most rehabilitation programmes involve some form of vegetation establishment (revegetation). Regardless of the land use objective, the chosen vegetation must be productive and sustainable. In areas where favourable environmental conditions prevail, natural succession may be the best option for restoration (Bradshaw, 1997; Cullen *et al.*, 1998; Prach and Pysek, 2001; Wiegleb and Felinks, 2001), but in arid and semi – arid regions appropriate intervention may be required (Le Houérou, 2000; Clewell and Aronson, 2007) to initiate and enhance the succession process.

At the study area, the East African Portland Cement Company has adopted various rehabilitation strategies to improve their environmental image and to avoid conflicts with the neighbouring communities where they carry out their activities. The Company's rehabilitation objective reflects an attempt to restore multiple land use values and species richness. The company also continuously identifies new ways to minimize its impact on the environment and promote its harmonious Industry/Nature co-existence, so that it leaves the environment in a better way than how it was initially. The study's revegetation plan for the site is therefore, intended to stabilize the soil, minimize erosion, enhance wildlife habitat, and increase the productivity and usage of the site.

Rehabilitation of mines is expensive, labour intensive, and slow to demonstrate results. If carefully planned, however, the coordination of scientific research, industry needs, and community land-use requirements will result in landscape reclamation that is productive and sustainable (Gough, Hornick and Parr, 1992).

2.7.1 Benefits of Quarry Rehabilitation

It is obvious that if land is restored to biological productivity or to a condition where it can once again be utilized for a range of purposes valuable to a community, it will represent a direct improvement of the area on which the restoration has been carried out. In addition, the surrounding areas will also benefit. The improvement of a mine site to a condition which integrates well into the surrounding landscape and removes intrusive landscape characteristics, upgrades the environment of a region far beyond the confines of the site that is restored.

Visual improvement of the area can begin to upgrade a whole range of environmental characteristics: the built environment is kept in better repair and road surfaces become worth maintaining, planning consents are more rigorously considered, and the general appearance is respected. Specific improvements of environmental conditions can also be added; reduction of dust in the air, reduction or elimination of gaseous additions to the atmosphere due to tip burning and reduction of particulate matter and noxious chemicals deposited in streams and water courses (Bradshaw and Chadwick, 1980; Kulshreshtha, *et al*., 2009).

The transformation that occurs in an area where planned and sensitive land rehabilitation is practiced enables whole communities and areas to begin to upgrade social and economic conditions. One improvement will follow another and amenities and facilities are improved.

2.7.2 Early Attempts at Mine Rehabilitation

Some 500 years ago, in his magnum opus, De re Metallica, Georgius Agricola (considered "Father of Mineralogy") said: *Now a miner, before he begins to mine the veins, must consider seven things, namely; the situation, the conditions, the water, the roads, the climate, the right of ownership and the neighbours* (Agricola, 1556), which reads almost like an environmental impact statement which demonstrates that the mining industry has espoused care for a long time.

The concept of rehabilitation of mining areas is not new. In the United Kingdom there were requirements to landscape old coal workings in the 18th century. Likewise, in the English Midlands from 1850, ironstone leases specified that worked out areas should be made fit for agriculture. In the United States of America there are records from about 1920 from Ohio and Illinois of attempts to plant over old coal tips (Vartanyan, 1989). It is only around 1960 that rehabilitation became widespread. Those showing particular concern include developed countries with large mining industries such as Japan, United Kingdom, USSR, USA and South Africa. Many developing countries have been willing to accept environmental disruption for the benefits of employment, wealth and raw materials supplied by the mining industry.

2.7.3 Current Practices in Mine Rehabilitation

One of the major environmental challenges in the new millennium is the legacy of many closed mines, especially in developing countries, which pose serious environmental hazard (Ghose, 1999). Today's rehabilitation objective reflects the multiple land use management, the expectations of the community and the rehabilitation techniques and capability, which have mostly been developed locally (Toy and Griffith, 2001). Haller Park in Bamburi, Kenya (Schoenborn, 2003), is a shining example of a developing country rehabilitation scheme motivated by making profit from an abandoned quarry. The performance of Bamburi has been largely driven from within, locally and beyond regulatory compliance and is working to transfer best practice and adopt the same rehabilitation principles and standards as used worldwide.

Currently one of the major constraints in rehabilitation programs in Kenya is the informal mining operations existing and the land tenure as far as the mines are concerned. In particular the licensing and administration of quarries leaves room for environmental malpractices.

2.7.4 Quarry Rehabilitation Success

Bamburi Portland Cement is located in Mombasa on the Kenyan coast. It is an excellent example of how ecological principles can be applied to obtain sustainable resource use for economic advantage and proves that mining need not necessarily ruin the natural environment. In Bamburi, Pleistocene coral limestone and Jurassic shale have been used as raw materials for production of cement since 1954. During the process vast tracts of land have been strip – mined and laid to waste. Dr Rene Haller, who was the Chief structural engineer at the Bamburi Portland Cement Company decided to embark on a quarry rehabilitation programme in 1970 (Haller, 1974). It included a fish farm, a crocodile farm and a biological water treatment area. *Casuarina equisetifolia* was found to be the ideal pioneer tree for the Bamburi conditions, and was planted intensively into the quarries. After more than 20 years the pioneer *Casuarinas* had fulfilled their task to transform the former quarries into a forest, with fertile soil and a balanced microclimate (Schoenborn, 2003; Sabine, 1996; Ayoti, 2009). Over the years, a great proportion of the site has been restored into coastal ecosystems of forests, grasslands and wetlands. More than 400 species of coastal indigenous trees have been introduced in the quarries as well as a variety of native animals (Haller and Baer, 1995). Several different animals have also colonized the developing ecosystem on their own accord. In 2007, the Bamburi team began planting bio-fuel trees as an outreach tool to promote carbon-neutral sources of energy for the cement kilns and integrating neighbouring communities.

Currently, no evidence remains of any industrial activity in the old quarries at Bamburi, which have become a good model for biodiversity (Siachoono, 2010). As well as being an ecological success, the Bamburi rehabilitation project has become an autonomous economically viable unit over the last several years and has had a higher profit margin than the cement factory.

Ngomongo Village is a well-known sustainable eco-cultural tourist village, located 10 km north of Mombasa Island in Kenya. In 1991 the Ngomongo quarry was a neglected wasteland measuring approximately 16 acres. This vast urban eyesore resulted from coral limestone mining. The 20 m deep quarry located 600 m offshore and with its floor approximately one metre above sea level, had been earmarked as the municipality's refuse dump site (Maybaum, 2003). Dr. Frederick Gikandi, a local medical doctor, applied Dr. Rene Haller's approach of Bamburi Portland Cement to rehabilitate the barren quarry. He reclaimed the quarry by planting 4 acres of eighty different indigenous trees; followed later by the easier to grow *Casuarina equisetifolia* trees. Currently the trees are of an average height of 10 m and above, and they provide a very good tree cover and shade for the quarry floor. The dropping foliage of these trees is broken down by micro–organisms and other small organisms like the millipedes. Public awareness on tree planting was raised by inviting the public to partner in the reclamation process. When the area was completely re-afforested, Dr. Frederick Gikandi invited 10 different local tribesmen to replicate their rural homes in the small clearings of the new forest. The outcome is now a well-known sustainable eco-cultural tourist village named Ngomongo Village (Mazera, 2009).

To date, Ngomongo Village rehabilitation project is fanning out its reclamation exercises to the surrounding farms by recruiting local farmers into planting trees to mark out their farm borders. The ultimate plan for Ngomongo is to fan out the success locally, regionally and eventually nationally.

The Walker Company of Kentucky in the United States operates a limestone quarry, which produces approximately 300,000 tons of limestone annually. The company has been recognized for its innovative and practical reclamation methods. Since mining began at the Menifee Stone site in 1961, the amount of acreage permitted for mining has more than doubled. After the vegetation and organic material is removed, about 30 cm of topsoil is separated and stockpiled. Next, approximately 60 m of overburden is removed and placed into empty pits. Within 180 days following the removal of limestone, reclamation of the quarry area is accomplished. Areas of the quarry are contoured to create gentle slopes. This is to slow the runoff of surface water, blend in with the surrounding topography, and to enhance the land’s use for hay and pasture (MII, 2010). The revegetation plan for the site was intended to stabilize the soil, minimize erosion, enhance wildlife habitat, and increase the productivity and usage of the site.

The Walker Company of Kentucky has made continual efforts and commitments to the reclamation of the Menifee Stone site. It is a site which is well maintained and serves as an excellent example of how quality limestone can be obtained in an environmentally sound manner.

2.8 Plants for Quarry Rehabilitation

The importance of plants in many terrestrial biomes is undisputed, as is their significance in providing ecosystem services and economic benefits (Raven and Andrews, 2010). The capacity of plants to reduce air pollution is also well known (Slinn, 1999; Sharma and Roy, 1997; Kulshreshtha, *et al.,* 2009). Plants provide an extensive canopy cover and establish a deeper root network that prevent soil erosion and help in the stabilisation of slopes. They are very important components of the hydrological cycle as they are the elements of evapotranspiration and they absorb carbon dioxide (CO_2) and contribute oxygen, resulting in the purification of the air. Plants also provide a high nutrient environment for grasses while reducing moisture stress and improving soil physical characteristics in arid and semi-arid climates (Belsky *et al.,* 1989; Tiedemann and Klemmedson, 2004).

A vegetation cover also goes a long way towards reducing the visual "scars" in the landscape caused by large-scale mining operations. Successful revegetation permits recreational use of the land and even for agriculture or forestry if conditions are favourable (Tordof *et al.,* 2000). Furthermore, the presence of plants in mine tailings enhances the heterotrophic microbial community, which may, in turn, promote plant growth and lead to metal stabilization (Mummey *et al.,* 2002; Glick 2003; Mendez *et al*., 2007).

Research into improving the success rate of revegetation of open-pit mines is vitally important, because it will lead to a decrease in the time needed to restore a quarried area to a near natural state. There is also a reduction in water erosion, wind erosion and subsequent dust generation. Any revegetation process comes at a cost. However, any expenditure can be minimized by implementing proven revegetation techniques and is amply repaid by the considerable benefits that flow from successful plant restoration, as seen in the case of the Bamburi Portland Cement rehabilitation project. Greater community understanding of ecological processes is leading to a demand that mined areas are restored in ways that are conducive to nature conservation, recreation and education.

Revegetation is the single most critical factor to a successful rehabilitation program. Therefore, understanding how to attain sustainable reclamation plant community systems is the paramount goal of this study. The key steps to successful reclamation, involves suitable substrate amendment and selection of appropriate plant species for revegetation.

2.9 Selected Plant Species for Rehabilitation of the Quarry Site

The establishment of a permanent cover of vegetation can fulfil the objectives of stabilization, pollution control and visual improvement (Wong, 2003). However, this effort involves not only growing plants, on mine wastes, but requires establishing a plant community that will sustain itself without further human intervention. Such performance could be achieved by selecting suitable plant species that can grow and reproduce under severe conditions.

The choice of exotic or native plant species in reclamation is very important, since newly introduced exotics may become pests in some situations. The selection of species that are well adapted to the local environment must be determined, and the economic importance of the choice species must also be considered. Nitrogen is a major limiting factor in mine degraded lands and addition of Nitrogen fertilizer becomes an essential practice to maintain healthy growth and persistence of vegetation. An alternative approach is to introduce local legumes and other Nitrogen-fixing species (Sprent and Sprent, 1990; Zhang, 1996). Nitrogen-fixing species can have a dramatic effect on soil fertility through the production of readily decomposable, nutrient - rich litter and turnover of fine roots and nodules (Diem, *et al*., 2000).

Growth rates of the species need to be assessed as the area needs to be reclaimed quickly. It is also necessary to locate drought tolerant species and ecotypes from different ecological zones for the restoration of mine wasteland. Based on the above *Acacia xanthophloea, Schinus molle*, *Casuarina equisetifolia* and *Grevillea robusta* plant species were selected for the rehabilitation of the limestone quarry in this study.

2.9.1 Acacia xanthophloea

Acacia xanthophloea is native to the study area, and is a nitrogen-fixing species. The behaviour of this species is well known and easily managed from planting to harvesting and it is the most widely used. It is widespread on river terraces, dry river courses and hilltops (ICRAF, 1992). It favours alkaline soils, can grow in shallow soil and produces deep roots penetrating a wide area to collect water (Coe and Beentje, 1991). This plant has root nodules containing nitrogen fixing bacteria as do most members of the Mimosaceae family and this play an important role in the nitrogen enrichment of soils and improves soil fertility, which then has a positive impact on the growth of plants around the fever tree (Smit, 1999). Other common attributes of acacia include their wide adaptability to different tropical environments, varying soil types and degrees of land degradation. *A. xanthophloea* comprises a dominant element of the tree flora in the vegetation of the arid to semi-arid savannas of Africa, where their foliage and pods provide forage for both domestic and wild herbivorous mammals (Coe and Beentje, 1991). The dappled shade underneath the canopy is ideal for smaller plants which require protection from the full brunt of the sun's rays but require sufficient light (Johhson and Johnson, 1993).

The most visible advantage of acacia lies in their various uses, (Otieno, Kinyamario and Omenda, 2001), ranging from timber, pulpwood and tannin in industry to fuel wood, fodder, food and shade for rural communities. These products can be obtained in a relatively short time due to acacias' fast growth. In addition to their value as food for domestic animals the people of Africa have used the leaves, pods, bark and gum of many acacia species for medicinal and mystical purposes for generations, while the wood and bark have been utilized for manufacturing baskets, drinking troughs, mats and a wide range of other household items. Other uses include the potential for honey production, in which acacia provide pollen, the main protein source for bee nutrition. This could be a valuable source of rural income but its effect remains undocumented (Oballa, Konuche and Thogo, 1997).

2.9.2 Casuarina equisetifolia

Casuarina equisetifolia is a drought and salt tolerant tree and is host to many microorganisms which fix nitrogen from the air and make it available to their host along with other nutrients. Therefore this enables Casuarina to grow virtually without soil and colonize greatly devastated areas (Anu, 2008). They are usually able to grow in nutrient-poor soils with low fertility by virtue of their ability to fix nitrogen in the root nodules through a mutualistic symbiosis which they form with the actinomycete *Frankia*, and their capacity to develop specialized structures of symbiotic origin known as mycorrhizas. The tree is very prolific, producing many seeds which germinate well. Therefore, it is very important for rehabilitation of poor soils. (El-Lakany and Yuness, 1996). *C. equisetifolia* has been successfully used for rehabilitation of the limestone quarries at the Bamburi Portland Cement Company, at the Kenyan Coast (Sabine, 1996; Ayoti, 2009).

C. equisetifolia has been widely used for shelterbelts and in landscaping as hedges and ornamentals, mainly planted as a tree along roadsides (Dahl, 1996). It can also be used as windbreak and as shade tree, green manure, bee-forage, fodder, and for sand dune stabilization, as well as soil rehabilitation and fertility restoration (El-Lakany and Yuness, 1996). The bark has been used in tanning and as medicine, and the fruits have been used for novelties and decorations. Root extracts are used for medical treatment of dysentery, diarrhoea and stomach-ache. With high productivity and properties that enhance soil fertility. *C. equisetifolia* shows promise as an agroforestry species for arid and semi-arid areas. In Kenya it is mainly used as building wood and the poles are in high demand in the local building industry (Kimondo, 1996).

2.9.3 Grevillea robusta

Grevillea robusta has been introduced to warm temperate, subtropical and tropical highland regions around the world commencing in the mid to late 19th century and is widely planted in many countries in Africa (Harwood, 1992). The natural distribution is in the warm humid to warm sub-humid climatic zones. However, the species has performed well when introduced to a much wider range of climates. It is one of the few tree species that has been successfully transferred from the humid highlands to the drier environment of the arid and semi-arid lands (ASALs). It is capable of extracting up to 80% of its water requirements from deep reserves during the dry season (Ong *et al.,* 1999).

In Kenya *G. robusta* is a popular tree already widely grown by farmers in Eco-climatic Zone IV. It is ever green and easy to propagate and establish and is relatively free of pests and diseases. It’s proteoid roots help it grow in low-fertility soils. It also provides economically valuable products including timber, poles, firewood and leaf mulch (Harwood, 1992). Other reasons for its popularity include the provision of poles, climatic improvement, erosion control, beauty, shade and provision of economic benefits. Other uses for *G. robusta* include the use of leaves and twigs as mulch in coffee plantations, as a substitute for manure since leaf fall is heavy, and as forage for bees. The leaves of *G. robusta* are also used by some farmers in the Embu district of Kenya as a fodder supplement for cattle in the dry season when other fodder sources are scarce. Before the advent of aluminium, the timber from this tree was widely used for external window joinery as it is resistant to rotting (Kalinganire, 1996).

2.9.4 Schinus molle

Schinus molle is fast growing and is an evergreen tree commonly planted in dry warm climates throughout the world. It will grow in almost any soil type. It is extremely drought resistant once established and reaches maturity in less than 20 years (Iponga, Milton and Richardson, 2008). *S. molle* grows in semi-arid lowlands, in dry, moist and wet, low, mid and highlands from near sea level to 2,400 m. It is native to the arid zone of Northern South America, Mexico and Peru's Andean deserts (Blood, 2001). It has, however, become widely naturalized around the world where it has been planted as an ornamental and for spice production (Iponga, Milton and Richardson, 2008).

In traditional medicine, *S. molle* was used in treating a variety of wounds and infections due to its antibacterial and antiseptic properties (Ferreroa, *et al.,* 2007). Recent studies have provided some support for its antidepressant effects (Machadoa, *et al.,* 2007). It has also been speculated that *S. molle*'s insecticidal properties make it a good candidate for use as an alternative to synthetic chemicals in pest control (Ferreroa, *et al.,* 2007). In Kenya it is mostly planted as an avenue tree along roadsides or as an ornamental. Other uses include firewood and charcoal production, bee forage, soil conservation, shade, windbreak and its leaves are used as an insect repellent.

2.10 Plant Nutrients in Soils

The most important considerations in revegetating reclaimed lands are soil pH, moisture availability, and the restoration of fertility and good nutrient cycling (Hall, 1980). The nutrients which plants use for growth and development are present in soils in form of elements in form of salts dissolved in soil water. Soils are formed from various types of rocks that are composed of various minerals. The type of soil in any location depends on the type of rock from which it has been formed as well as the amount or extent of erosion (weathering) that has taken place. In essence, the chemical elements contained in the rock minerals that form soil are usually contained in the inorganic framework of such soils.

Invariably, all the mineral elements known in chemistry are present in soils. However, only a few of them have been proved to be essential for plant growth. These elements are usually grouped into two on the basis of the quantities required by plants. One group includes those that are required by plants in large amounts which are termed as “macronutrients”. These include elements frequently applied in various forms as fertilizers to stimulate growth, including Nitrogen, Phosphorus, and Potassium. It also includes those elements found abundantly in soils, and which are not often limiting to plant growth, such as C, H, O, Ca, S and Mg. The remaining essential elements include Fe, B, Mn, Zn, Mo and Cl which are termed “micronutrients” as they are needed in very small quantities and may be harmful or toxic to plants if present in large quantities in the soil. According to Akinrinde (2004) optimum plant nutrition demands that the required nutrients should be present and made available to plant roots in the soil in the required quantities.

2.10.1 Nutrient Availability in Relation to Soil pH

The pH value of soil is very important as it has a direct influence on the health of the plant. The reason for this is that soil pH affects the availability of nutrients within the soil and plants have different nutrient needs. For example the nutrient Nitrogen, is readily available in soil when the pH value is above 5.5. If a plant is grown in a soil lacking in nutrients that it needs, this will promote disease. Many plant diseases are caused or exacerbated by extremes of pH, this makes essential nutrients unavailable to crops. Chlorosis of leaf vegetables and potato scab occur in overly alkaline conditions, whereas acidic soils can cause clubroot in brassicas. In general the optimum pH value range for soil is approximately 6 - 7 as this is the range in which most nutrients can be readily available (Smith e*t al.*, 1994).

Many nutrient cations such as zinc (Zn^{2+}), aluminium (Al^{3+}), iron (Fe^{2+}), copper (Cu^{2+}), cobalt (Co^{2+}), and manganese (Mn^{2+}) are soluble and available for uptake by plants below pH 5.0, although their availability can be excessive and thus toxic in more acidic conditions (Havlin, 1999). In alkaline conditions they are less available, and symptoms of nutrient deficiency may result, including thin plant stems, yellowing (chlorosis) or mottling of leaves, and slow or stunted growth (Loeppart *et al*., 1984). pH levels also affect the complex interactions among soil chemicals. Phosphorus for example requires a pH between 6.0 and 7.5 and becomes chemically immobile outside this range, forming insoluble compounds with iron (Fe) and aluminium (Al) in acid soils and with calcium (Ca) in calcareous soils (Bohn *et al*., 2001).

2.11 Soil Moisture Content

Soil moisture indicates the ability of a soil to hold water. Soil moisture impacts on the distribution, growth of vegetation, soil aeration, soil microbial activity, soil erosion and the movement of nutrients in the soil to the roots. Every plant has a preference when it comes to soil moisture (Shaxson and Barber, 2004).

Plants consume large amounts of water and water uptake by trees is considered to be the main determinant of soil water depletion in the adjacent soil volume (Broadhead *et al.*, 2003; Radersma and Ong, 2004). Although trees may increase soil water content in the rooting zone by increasing ground cover and thereby reducing soil evaporation, or by accessing water in the deeper horizon and subsequently releasing it in the surface horizons through the process of hydraulic lift (Burgess *et al.*, 1998; Jackson *et al.*, 2000), they may also decrease soil water content through their own uptake and transpiration of water (Broadhead, 2000).

2.12 Soil Organic Matter Content

Soil organic matter is defined as the organic fraction of soil including plant and animal content, as well as microbial residues at all stages of decomposition including fresh and humus fractions (Bashour and Sayegh, 2007). Organic. matter has been termed the "life blood" of soils. It has a tremendous impact upon the chemical, physical and biological properties of the soil. Soils vary greatly in their organic matter content (Tiessen, Cuevas and Chacon, 2002). Climate affects the array of plant species, the quantity of plant material produced and the intensity of soil microbial activity. Arid and semi arid soils have very little organic matter content. The organic fraction of soil is less than 5% living microbes, plant roots and soil fauna and greater than 95% dead plant and animal residues (Bohn *et al.,* 2001). Per unit mass, the organic fraction is the most chemically active portion of the soil. It is a reservoir for essential elements (particularly Carbon, Nitrogen, and Phosphorus), promotes good soil structure, is a source of cation exchange capacity and soil pH buffering, promotes good air-water relations in soils, and is a large and active reservoir and buffer of carbon in the environment.

CHAPTER THREE: MATERIALS AND METHODS

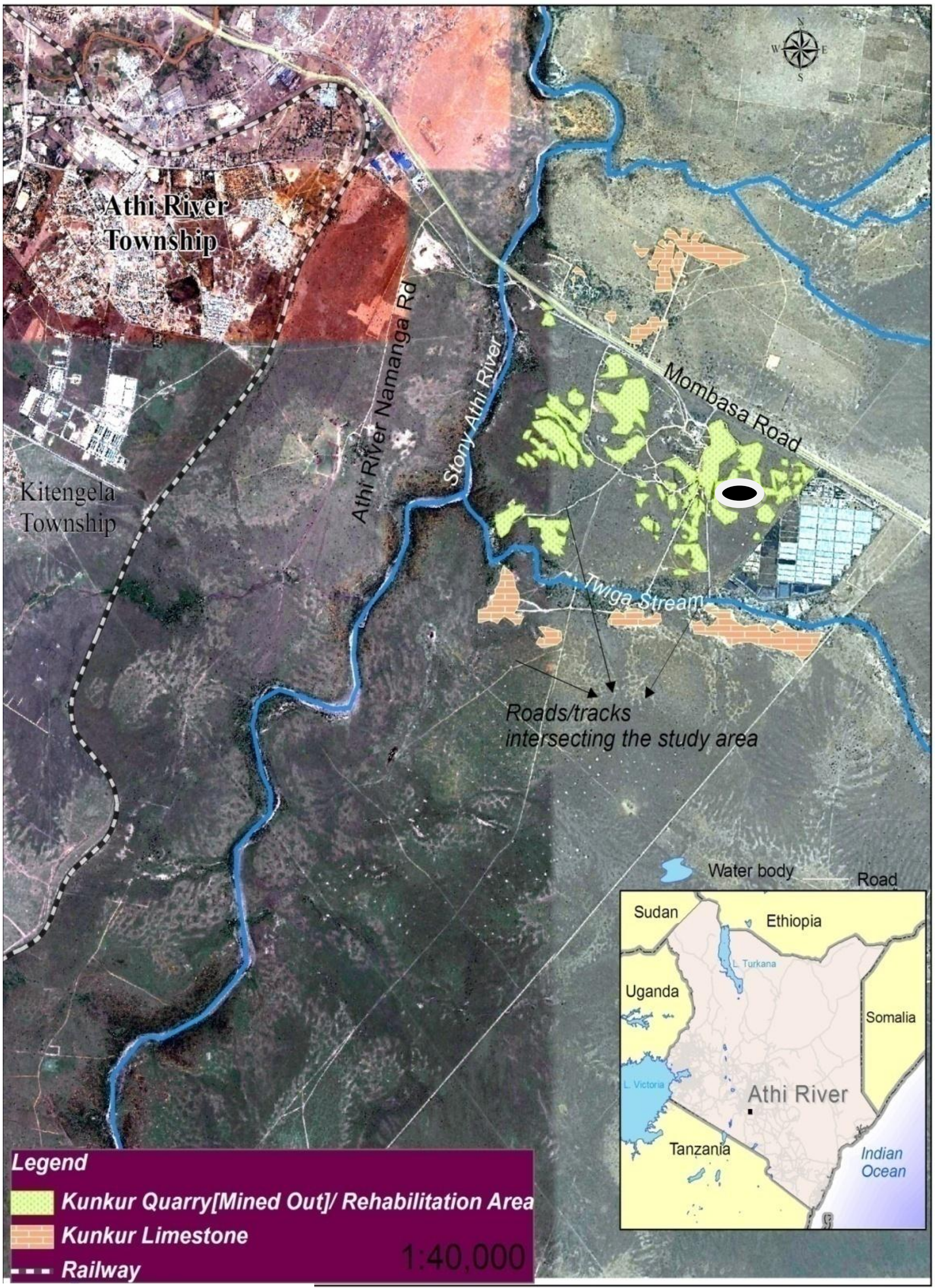
3.1 Introduction

The chapter describes the study area and the experimental design adopted for the study. Tree establishment, management, assessment procedures, and characteristics of the trees selected are also given. Finally soil sampling procedures and analysis are presented.

3.2 Study Area

3.2.1 Location

The study area is situated in Athi River, Machakos District, approximately 30 km South-East of Nairobi and is adjacent to the main A109 Nairobi-Mombasa road. It lies between latitude 1° 26’46’’ S and 1° 32’ 10’’ S and is bounded by longitudes 36° 58’ 24’’ E and 37° 03’08’’ E. It covers an area of approximately 15 km^2. It lies at an altitude of 1,500 metres above sea level. On the northern side, an all weather road, the main A109 Nairobi-Mombasa road serves the study area. On the western side, it is bounded by the Mombasa Railway line. Several dry weather roads and footpaths serve the area (Figure 3.1)



STUDY SITE

Figure 3.1 An illustration of the mined out kunkur Quarry (study site), developed from setallite imagery of Landsat TM year 2008. The map shows Athi River and the sourrounding area including other land use and landcover types.

3.2.2 Physiography

The area is generally flat and characterized by a gently sloping terrain, which descends towards the north to Athi River. The Athi River flows southeast from the Nairobi National park and is joined by Kitengela River just inside the western boundary of the urban council. The river turns in a north easterly direction where it is joined by stony Athi River approximately 8km from Athi River Town.

The general relief and drainage pattern is from southwest to northeast. The Stony Athi and Twiga streams cut across the study area. The groundwater recharge is through infiltration, subsequent percolation and regional lateral flow from the higher areas west of the study area. Seepage from the Athi River and its tributary contribute towards the recharge of the underlying volcanic rock formation. The soil is black cotton clay soil with a high content of sand (APCM, 1977).

3.2.3 Climate

According to Sombrock *et al.,* (1982), the study area falls under ecoclimatic zone IV, with the mean annual temperature of 18 ^{0}C to 20 ^{0}C. The mean annual maximum temperature range is 24 ^{0}C to 26 ^{0}C with a minimum range of 12 ^{0}C to 14 ^{0}C. The average annual rainfall and average annual potential evaporation are 450 – 900 mm and 1650 – 2300 mm, respectively. The potential for plant growth is considered to be medium to low. The area is characterized by low moisture content. The rainfall is bimodal with short the rains occurring in October to December while the long rains are received in March to May (Njoroge and Macharia, 2007).

3.2.4 Vegetation

The study area consists of sparse vegetation cover (Plate 3.1) consisting of grasslands with a few scattered thorny acacia trees, mainly *Acacia tortilis* and A*cacia xanthophloea*. *Acacia xanthophloea* was selected for this study because it is a fast-growing tree that is widely distributed in the dry parts of the country.

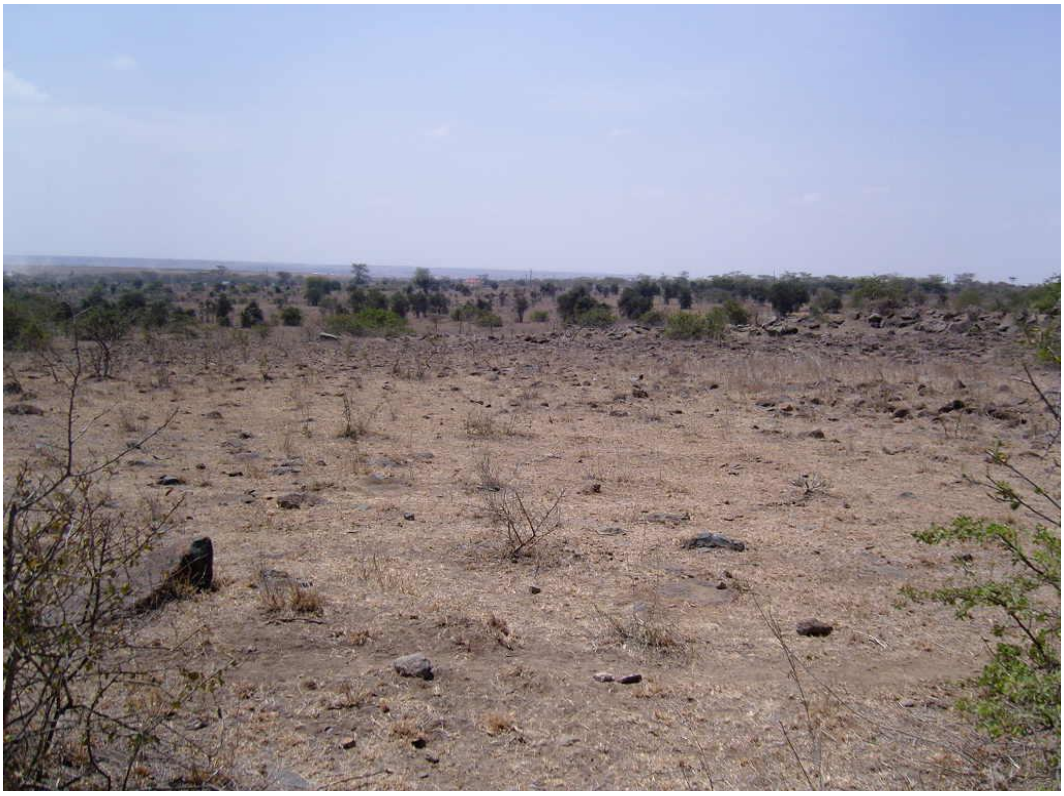


Plate 3.1 Sparse vegetation cover at the study area

3.2.5 Geology

The study area forms part of the physiographic unit known as the “Athi Basin” which comprises those areas drained by the Athi River, Stony Athi, Isinya and Kitengela rivers. The basin is underlain by metamorphosed sequences of Pre-Cambrian gneisses, quartzites and subordinate limestone. These have been subjected to repeated uplift and erosion resulting in the formation of the sub-Miocene peneplain on which the Tertiary volcanics, represented principally by the Kapiti Phonolite and Upper Athi Tuffs were deposited. The Kapiti Phonolite and Upper Athi Tuffs are the principal volcanic rocks represented in the area (Saggerson, 1991).

The formation of kunkur limestone appears to be a late phase in the weathering cycle associated with the concentration of carbonates in solution and it’s precipitation as crystalline lenses and nodules in a tuffaceous matrix and as powdery nodules in clay. Prolonged deposition of carbonate in certain areas resulted in the coalescence of nodules to form a hard highly calcareous caprock (APCM, 1977). The kunkur formation as exposed in the quarry has an average thickness of approximately 3 metres with overburden of 1 to 1.5 metres of soil. In most cases the kunkur formation comprises of 1 metre of caprock, underlain by medium grade kunkur nodules in a tuffaceous clayey matrix. This material usually passes down into low grade kunkur, containing sporadic crystalline kunkur nodules and lenses.

Black cotton soil, which is indicative of poor drainage, predominates in areas where kunkur limestone deposit is present, while sandy and clayey soils overlie the phonolites and tuffs respectively (APCM, 1977). The development of the present drainage system has resulted in the local erosion of black cotton soil and kunkur.

3.2.6 Quarry Development at the Study Area

Quarrying activities at the study area are carried out by mechanized means. Topsoil overburden is removed by scrapers and taken to the waste dump yards, located nearby on non - mineralized zones (Plate 3.2a and b). Cap rock, where present, is blasted and ripper bulldozers are used for dozing and ripping the kunkur layer beneath. The loosened material is then heaped up for loading by wheel loaders into dump – trucks for onward transport to the crushing and screening plant. The crushing and screening plant rejects -6 mm material. The +6 mm material and the caprock are sent separately to the Athi River cement works (APCM, 1977).

(a)

(b)

Plate 3.2 (a) and (b) shows limestone quarry waste dump yards, of various age, located on non - mineralized zones at the study area. Plate (b) shows relatively more recent limestone waste as compared to Plate (a).

3.3 Selection of Plant Species

Plant species native to Athi River area have been widely recommended as desirable species for revegetation, due to the fact that native vegetation is an expression of adaptation to both local soil and climate. However, studies have shown that utilization of introduced species can increase productivity considerably as compared to native stands of vegetation, and introduced species are at times favoured over native species because of their aggressive growth and high productivity (Sarrailh, 2001). *Acacia Xanthophloea, Schinus molle, Casuarina equisetifolia and Grevillea robusta* species were selected, because of their good adaptability, easy propagation, good water and nutrient economy, high productivity, good re-sprouting ability after cutting and high resistance against injury caused by biotic and abiotic agents. The species have also been found to improve soil fertility, the microclimatic condition, and provide protection against wind and are used as a source of fuel among other benefits.

Acacia Xanthophloeas 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 in the 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, Milton and Richardson, 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).

3.4 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, at the Kenya Forestry Research Institute (KEFRI), Muguga. To initiate germination, all seeds were immersed in boiled water and left to cool overnight, before being planted in trays filled with soil (Palzer, 2002). 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 to try and simulate as far as possible the soil conditions in the study area (Oballa, Konuche and Thogo, 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 (Plate 3.3).

Plate 3.3 Tree Seedlings Nursery at three months

3.5 Field Experimental Designs

The experiment was designed to determine growth rates of *A. Xanthophloea, S. Molle*, *C. equisetifolia* and *G. robusta* species in a kunkur limestone quarry. 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 Randomised Complete Block Design (RCBD).

Four sub-blocks were then created in blocks A, B, and C, and in each sub-block, 20 holes, measuring 40 cm x 40 cm x 40 cm each, were dug one metre apart in a row (Figure 3.2). 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 sub-block, on 23rd March, 2006.

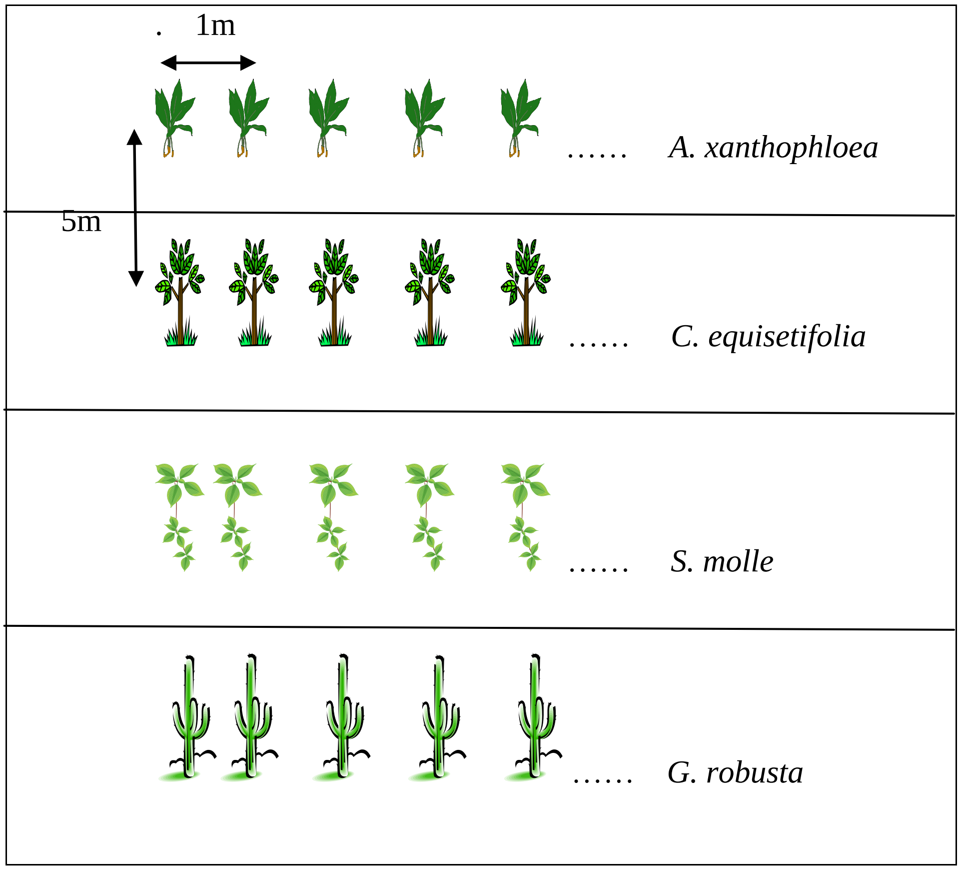


Figure 3.2 Experimental Layout for *Acacia xanthophloea, Casuarina equisetifolia Schinus molle and Grevillea robusta,* showing within the block design.

The sequence of planting the four species in the sub-blocks was varied from block to block. Block D was left unplanted for the control. Figure 3.3 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.

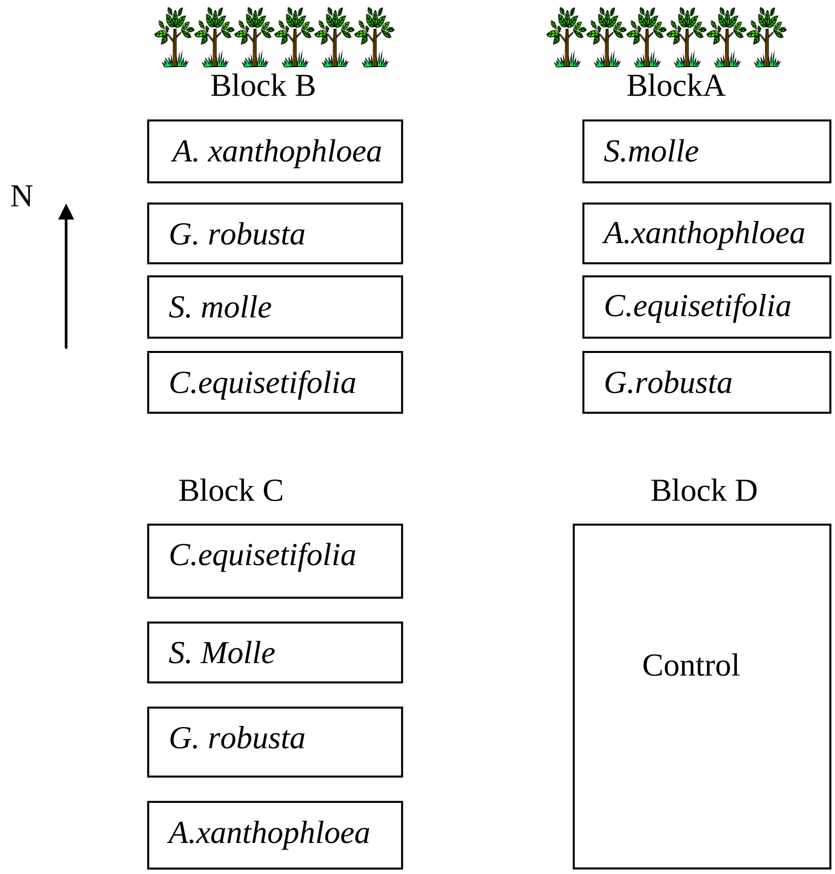


Figure 3.3 Experimental Layout for *Acacia xanthophloea*, *Casuarina equisetifolia Schinus molle and Grevillea robusta*, planted in blocks A, B, and C. Block D was left unplanted for control.

3.6 Growth Analysis

Seedling height (cm) and stem diameter (cm) were measured immediately after planting on 23rd March, 2006, and thereafter measurements were recorded every two weeks. This was continued from 23rd March, 2006 to 23rd March, 2008. 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 (Plate 3.4). A Vernier calliper was used to measure basal stem diameter 1 cm above the soil surface. A line was painted on the trunk using water paint, 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).

Plate 3.4 Tree measurement, *Acacia xanthophloea* at 18 months

3.7 Soil Sampling

After back filling 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. Soil sampling was again conducted immediately after tree planting in March 2006 and thereafter every six months until 2008. In block A, B and C, soil samples were collected using an auger for 0 - 15cm, 15 - 30cm and 30 - 45cm horizons, at distances of 0.5 m, 1.5 m and 2.5 m from the planted tree lines. The horizons represented part of the soil where most roots are present and most nutrient absorption occur (Bashour and Sekayange, 2007). Samples taken from the same distance and depth on either side of the tree line were bulked to provide a single composite sample. The composite sample was divided into two parts; one part for the determination of moisture content and the other part was oven dried and stored in plastic bags for analysis of other soil parameters. Samples were also collected randomly from (Block D) from 0 - 15 cm, 15 - 30 cm and 30 - 45 cm horizons for control (Figure 3.3). Different sampling locations were used for each sampling date.

3.8 Physical Soil Analysis

3.8.1 Soil Moisture Content

Soil moisture content was determined gravimetrically (Noborio, 2001). Twenty grams of soil samples were taken and oven dried at 105 ^{0}C for 24 hours, cooled and reweighed. The change in soil weight was taken to correspond to loss of water, and soil moisture content was then calculated on dry weight basis (Gardner, 1986).

3.8.2 Soil Organic Matter Content

Organic matter in the soil was determined using the method described by Anderson and Ingram (1993). Five grams of soil samples were transferred into a 250 ml beaker, 10 ml of potassium dichromate was added followed by 20 ml concentrated sulphuric acid and mixed thoroughly for 1 minute and left to stand in the dark for 30 minutes. Two hundred millilitres of water was added followed by 10 ml of orthophosphoric acid and 1 ml of dimethyamine indicator and mixed thoroughly. The mixture was then titrated with ferrous sulphate until the colour changed from blue to green. A further 0.5 ml of potassium dichromate was added until the colour changed back to blue and the mixture again titrated with ferrous sulphate until the colour changed to green. The volume used was recorded to the nearest 0.05 ml.

The total volume of potassium dichromate used to oxidize the organic matter in the soil was than calculated.

3.9 Chemical Soil Analysis

3.9.1 Soil pH

The air-dried sample was passed through a 1/8 inch (3mm) B.S test sieve. Ten grams of soil obtained was weighed out into a 50ml beaker. Twenty five millilitres of distilled water was added to it and the suspension stirred for a few minutes and allowed to stand over-night. The sample was then stirred again immediately before testing (Rhoads, 1982). The pH of the suspension was measured using a Jenway UK pH meter Model 3510 serial number, 30106.

3.9.2 Soil Exchangeable Cations

Exchangeable cations (Na, K, Ca, and Mg) in the soils were extracted using excess ammonium acetate (NH_4OAc). Hundred millilitres of ammonium acetate solution was added to 5g of the soil sample and then mixed thoroughly for 30 minutes and filtered through a Whatman filter paper No.42. Exchangeable Na and K were determined using UK, Flame Photometry model number BWB-XP. While concentrations of exchangeable Ca and Mg were determined using Atomic Absorption Spectrophotometer PG Instrument Limited, UK, model number PG – 990. Similar treatments were done to the blank samples. This was carried out at the chemistry laboratory at Mines and Geology Department, Ministry of Environment and Mineral Resources.

3.9.3 Soil Total Phosphorus

Determination of total Phosphorus followed the method described by Olsen and Sommers (1984). To 1 g of soil sample, 10 ml water was added and mixed to form a slurry mixture. One ml concentrated sulphuric acid and 5 ml nitric acid was added and the sample digested for 2 hours using a hot plate. The mixture was then cooled and the pH was adjusted to 6.5 -7.5 by adding 20 ml distilled water. Ten millilitres of the digested sample was transferred to a 50 ml volumetric flask and 25 ml of distilled water was added and allowed to stand for 5 minutes. The percent transmittance for the sample was read at 430 nm on a UV/Visible Spectrophotometer PG Instrument, UK Model number T80. The blank sample was treated similarly. This was also carried out at the chemistry laboratory at Mines and Geology Department, Ministry of Environment and Mineral Resources.

3.9.4 Soil Total Nitrogen

Organic nitrogen was converted to ammonium ion by digestion using sulfuric acid with copper sulphate as catalyst. The solution was then made alkaline with sodium hydroxide and the free ammonia was distilled off and Nesslerized. The colour developed is proportional to the organic nitrogen content. Colour intensity was measured colorimetrically using a digital grating spectrophotometer (Model, CE 2343D). Standards of known NO_3-N concentration were subjected to the same treatment. This was carried out at the Chemistry Department, Kenyatta University.

3.10 Meteorological Data

Daily rainfall data from the year 2005 to 2008 were obtained from a nearby flower farm in Athi River meteorological stations managed by the Kenya Meteorological Department.

3.11 Data Analysis

Data compilation and analyses was carried out using Microsoft Excel, SPSS and Genstat Discovery Edition 3, software packages. Descriptive statistics, frequency, comparisons of means, standard deviations, multivariant numerical methods and analysis of variance (ANOVA) were all used where appropriate for specific research objectives to test for differences between variables and treatments.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter focuses on the study findings on the performance of selected tree species and how they influence physical and chemical conditions of the material used to fill a limestone quarry. The results were subjected to analysis of variance for a randomized complete block design, using GENSTAT discovery Edition 3, and SPSS to establish significant treatment effects (Kuehl, 1994; Montgomery, 1996).

4.2 Chemical Composition and Fertility Status of the Material used to Backfill the Quarry

It was observed that the soils in the study area (Table 4.1), 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 4.1 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).

Landon (1991) noted that the soil pH tolerance limits of different plants varied greatly, but for most plants pH value of between 6.3 and 7.5 was most suitable. In the presence of calcium, phosphate tends to be converted to calcium phosphates at high pH values (>8.0), and availability of Phosphorus to plants is reduced. Micronutrient availability is also reduced with increasing pH values.

The levels of exchangeable cations (Ca, Mg, Na, and K) in the soil are usually of more immediate value, because they not only indicate existing nutrient status, but can also be used to assess the balances amongst cations. This is of great importance because many effects, on soil structure and on nutrient uptake by crops, are influenced by the relative concentrations of cations as well as by their absolute levels (Landon, 1991). The effects of the exchangeable cations in soils on plant growth are often closely interlinked. For optimum plant growth, the total, as well as the proportion of different nutrients play a major role. Chege (1982), noted that the proportions of Ca, K and Mg in relation to one another is important in that an oversupply of one may hinder the uptake of the other resulting in deficiency although the element exists in adequate amounts in the soil. At the study site, the Ca:Mg ratio was approximately 5:1 and this will probably result in the decreased availability of Mg with increasing Ca cation (Landon, 1991).

Iron is the most commonly deficient nutrient on calcareous soils. Lindsay and Schwab (1982) stated that low Fe availability on calcareous soils results from low concentrations of dissolved inorganic Fe at the pH range of calcareous soils and the reaction of Fe with $CaCO_3$ forming insoluble Fe-oxides. The very low solubility of these compounds means that Fe concentrations in soil solutions are also very low. The manifestation of Fe deficiency on calcareous soils are Fe – chlorosis, but plants vary in their tolerance to Fe – chlorosis (Loeppart *et al*., 1984). At the study site possible Fe deficiency was observed in some of *C. equisetifolia* foliage.

Decreased availability of soil Mn, Zn, and Cu is also associated with calcareous soils, and decreased availability of these elements probably resulted from both pH effects and interaction with the soil carbonates (Talibudeen, 1981; Marschner, 1995). Similarly Fe, inorganic Mn and Zn are less soluble in the alkaline range of pH and are precipitated as carbonate minerals (Aguila, 2007). According to Landon (1991), the action of Mn is also highly dependent on the presence of other ions; Mn can induce Fe chlorosis and there is some evidence which suggests that Fe and Zn can also interfere with Mn uptake.

4.3 Growth Performance of the Selected Plant Species

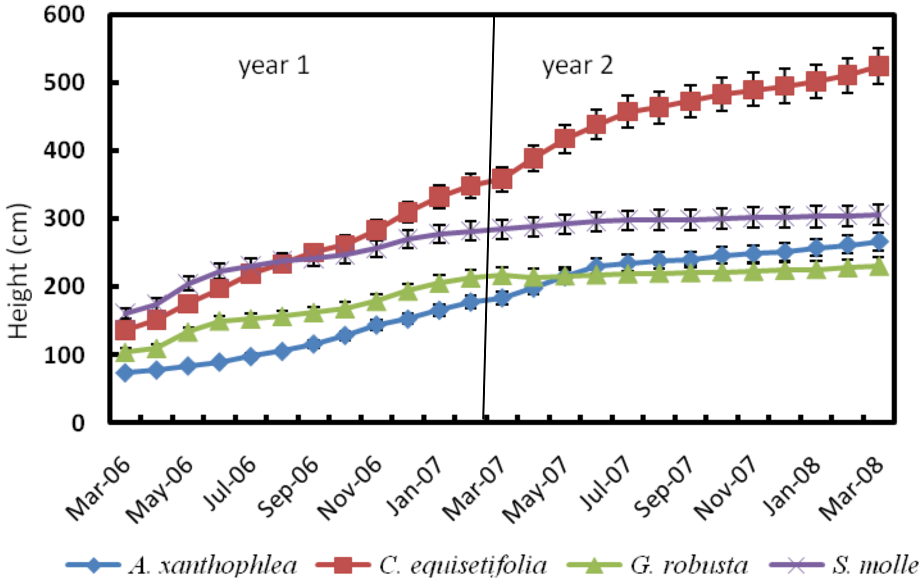
Information on the growth patterns for individual tree species is an important tool to determine adaptation in specific environments and systems (Muthuri, 2004), and to determine tree performance. Plant growth was estimated as the increment of the tree height, diameter at the stem base, and diameter at breast height (Clemente *at el.*, 2004), during the study period between March 2006 and March 2008.

4.3.1 Tree Height

Casuarina equisetifolia recorded the highest height of 348.8 cm at the end of year 1 of planting (Figure 4.1a), followed by *S. molle* (281.9 cm), *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 of 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 were significantly ($p<0.001$) higher for *C. equisetifolia* (17.12 cm/month) at the end of the first year of planting (Figure 4.1b), followed by *S. molle* (9.55 cm/month), *G. robusta* (8.73 cm/month) *and A. xanthophloea* (7.72 cm/month). In year two of 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).

(a) Timecourses of Tree Height



(b) Growth Rate

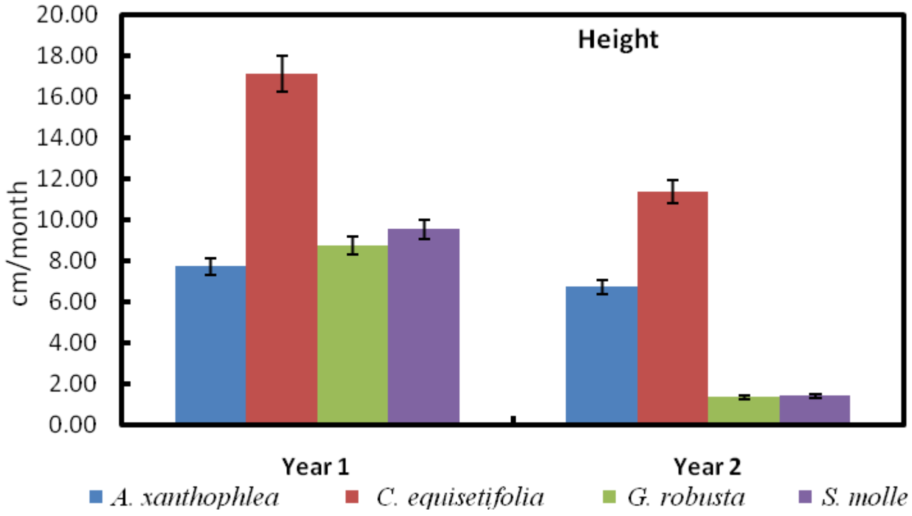


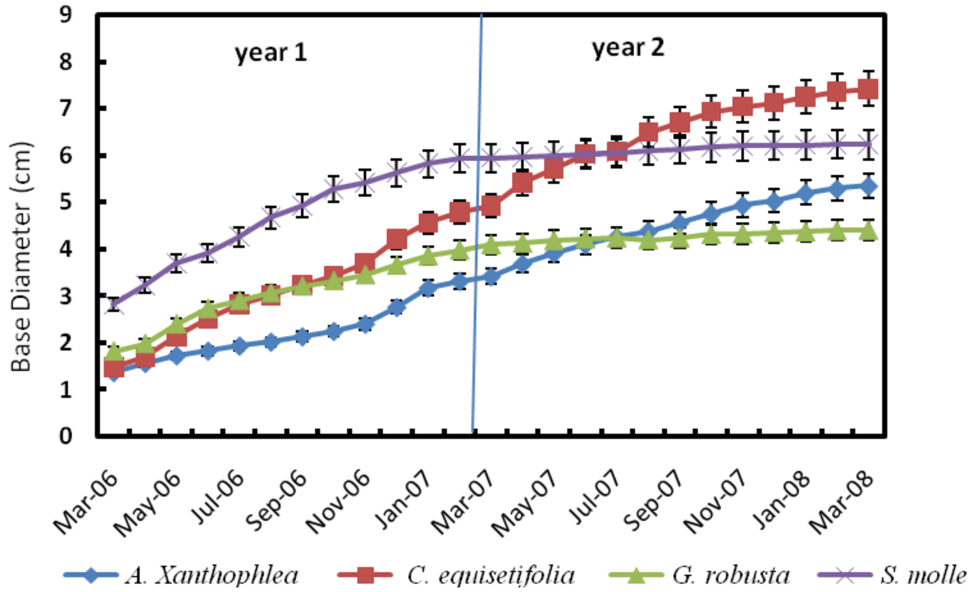
Figure 4.1 (a) Timecourses of Tree Height, and (b) Growth Rate, for *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle* during the two year period after planting. The vertical bars represent standard error of the mean.

ANOVA 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.

4.3.2 Basal Stem Diameter

At the end of year 1 of planting, *S. molle* recorded a significantly ($p<0.001$) the 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 (Figure 4.2a). Growth rates for BD after year 1 of planting, were 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) (Figure 4.2b). 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).

(a) Timecourses for Basel Stem Diameter



(b) Growth Rate

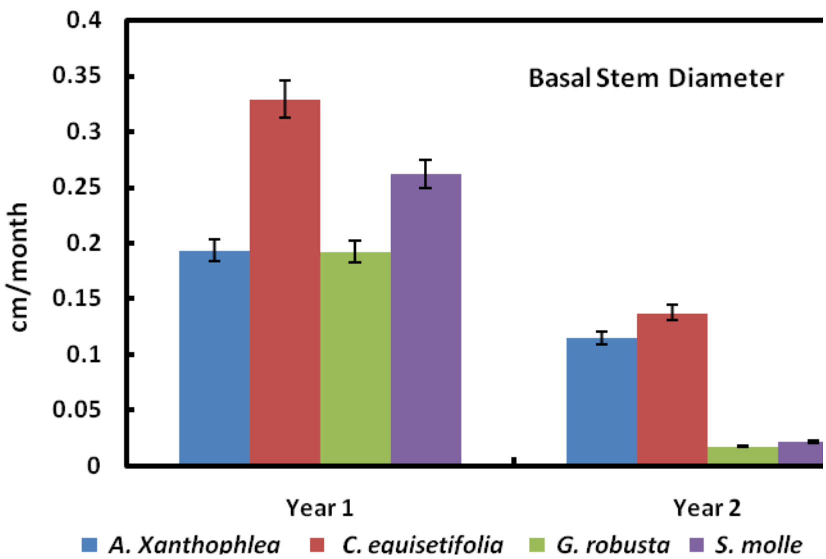


Figure 4.2 (a) Timecourses for Base Stem Diameter, and (b) Growth Rate, for *A. xanthophloea, C. equisetifolia, G. robusta* and *S. molle* during the two year period after planting. The vertical bars represent standard error of the mean.

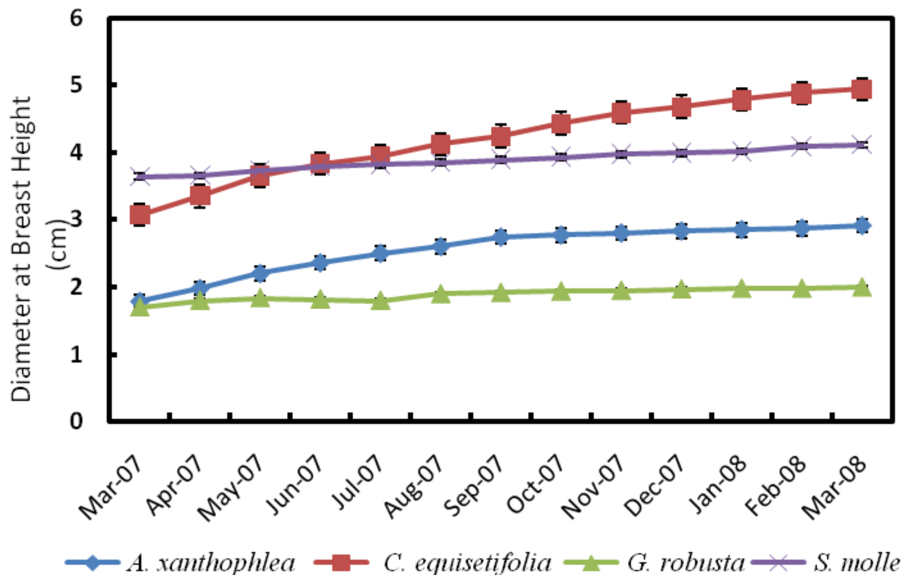
ANOVA showed significant differences between species ($p<0.001$), and between time-species ($p<0.001$), indicating continuous tree growth for all the species. Basal stem diameter was characterised by marked increase during the first year of planting and a reduced rate of increase during the second year 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.

4.3.3 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 (Figure 4.3a). This was followed by *S. molle* (4.11 cm), and *A. xanthophloea* (2.91 cm). DBH was consistently lowest in *G. robusta* (2.00 cm). Growth rates for DBH showed significant differences (Figure 4.3b), 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).

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

(a) Timecourses for Diameter at Breast Height



(b) Growth Rate

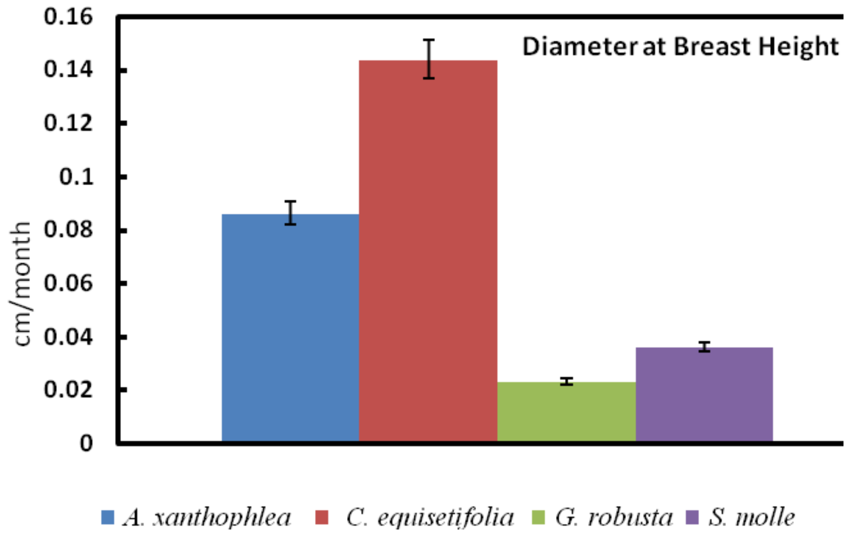


Figure 4.3 (a) Timecourses for Diameter at Breast Height, and (b) Growth Rate, for *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle* from May 2007 to May 2008 during the second year of planting. The vertical bars represent standard error of the mean.

All the tree species recorded steady increments for height, 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 4.2, 4.3, 4.4 and 4.5). Within species, differences between plants may have resulted from adjustments in those strategies that are determinant of plant performance under drought conditions.

Plate 4.1 *Casuarina equisetifolia* at 24 month after planting

Plate 4.2 *Acacia xanthophloea* at 24 months after planting

Plate 4.3 *Schinus molle* at 24 months after planting

Plate 4.4 *Grevillea robusta* at 24 months after planting

Schroth (1999) noted that tree root systems in general, and fine roots in particular, contribute to some of the major beneficial effects on soils. These include enrichment of the soil carbon pool as a result of root turnover (Kang, 1997), mycorrhizal activity (Dommergues, 1995), interception of leached nutrients and runoff (Hauser and Kang, 1993; Schroth *et al.*, 2001) and physical improvement of compacted soil horizon (Buresh and Tian, 1997). Trees can improve soil productivity (Sanchez 1995; Binkley, 1996). Nitrogen - fixing trees may increase the supply of available Nitrogen in the soil, benefiting both Nitrogen-fixing and non-Nitrogen-fixing trees. High rates of Nitrogen-fixing may require relatively high supply rates of soil Phosphorus, high Phosphorus supplies support greater nodule, and hence, more rapid tree growth (Binkley, 1996; Binkley and Giardina, 1997).

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 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. Similar results were also observed by Hagstrom *et al*., 2001; Liang and Li, 2003. This was also observed when *C. equisetifolia* was used in rehabilitating a formerly barren fossil coral limestone quarry near Mombasa, Kenya. It was also recorded that *Casuarina* trees led to improvement of conditions at the quarry, allowing other species to grow, and resulting in luxuriant vegetation (Diem *et al*., 2000).

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 inadequate water and nutrients supplies, or that the trees may not have developed sufficiently rooting system to sustain the demands of the crown for water and the failure of roots to penetrate the compacted mine floor soils. Calcareous soils may be compacted or cemented at depth (Lavagne and Moutte 1966) and may form surface crust that may inhibit seedling emergence and growth (Hager and Seighardt, 1984; Marion *et al*., 1993). This may exhibit physical effects on root penetration, water infiltration and gas exchange. 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 (Figure 4.1a). 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 (Johhson 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 (Abulfatih and Hashish, 1995). *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.

4.4 The Influence of Tree Species on the Soil Moisture Content (Soil Physical Properties)

The study area was characterized by erratic and poorly distributed rainfall throughout the duration of the research (Figure 4.4). Total rainfall during the first year of planting was 762.8 mm and for the second year 690 mm. There were periods of short flushes of heavy rainfall received over a few days during the months of November and December 2006. March 2007 recorded the highest total rainfall (298.5 mm).

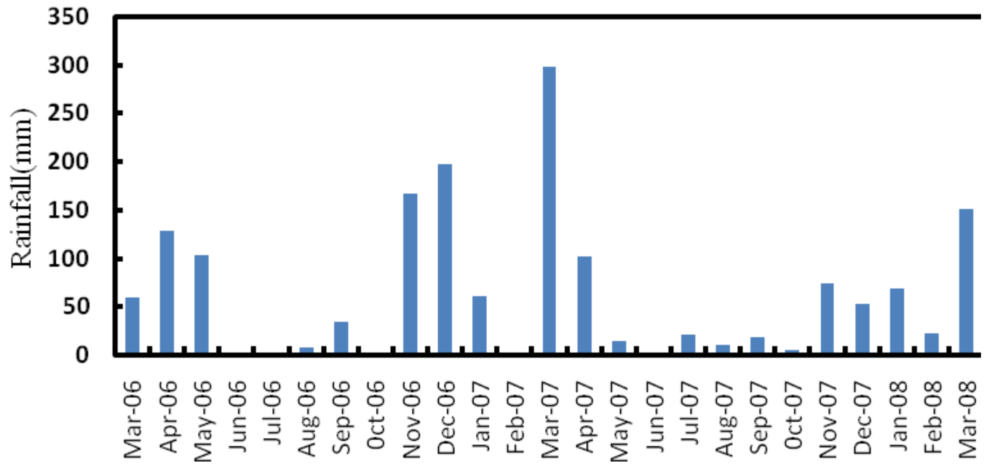


Figure 4.4 Total monthly rainfalls between March 2006 and March 2008 during the observation period.

The soil moisture content was low as compared to tropical soils, under all the tree species through-out the observation period, and ranged from 0.67% to 2.30%, but was substantially greater than in the control treatment which recorded a mean value of 0.626% (Figure 4.5). Soil moisture content closely correlated with rainfall, increasing during periods of high rainfall (March 2007), and declining, particularly between June 2007 and October 2007 when rainfall was low.

At the end of year 2, soils collected from under *C. equisetifolia* from 0-15 horizon and at 0.5 m from the tree row recorded the highest soil moisture content (2.3 %), followed by *S. molle* (2.05 %), *A. xanthophloea* (2.15 %) and *G. robusta* (1.99 %). The trends for, 15 – 30 cm and 30 – 45 cm horizons were also similar to those shown in Figures 4.5.

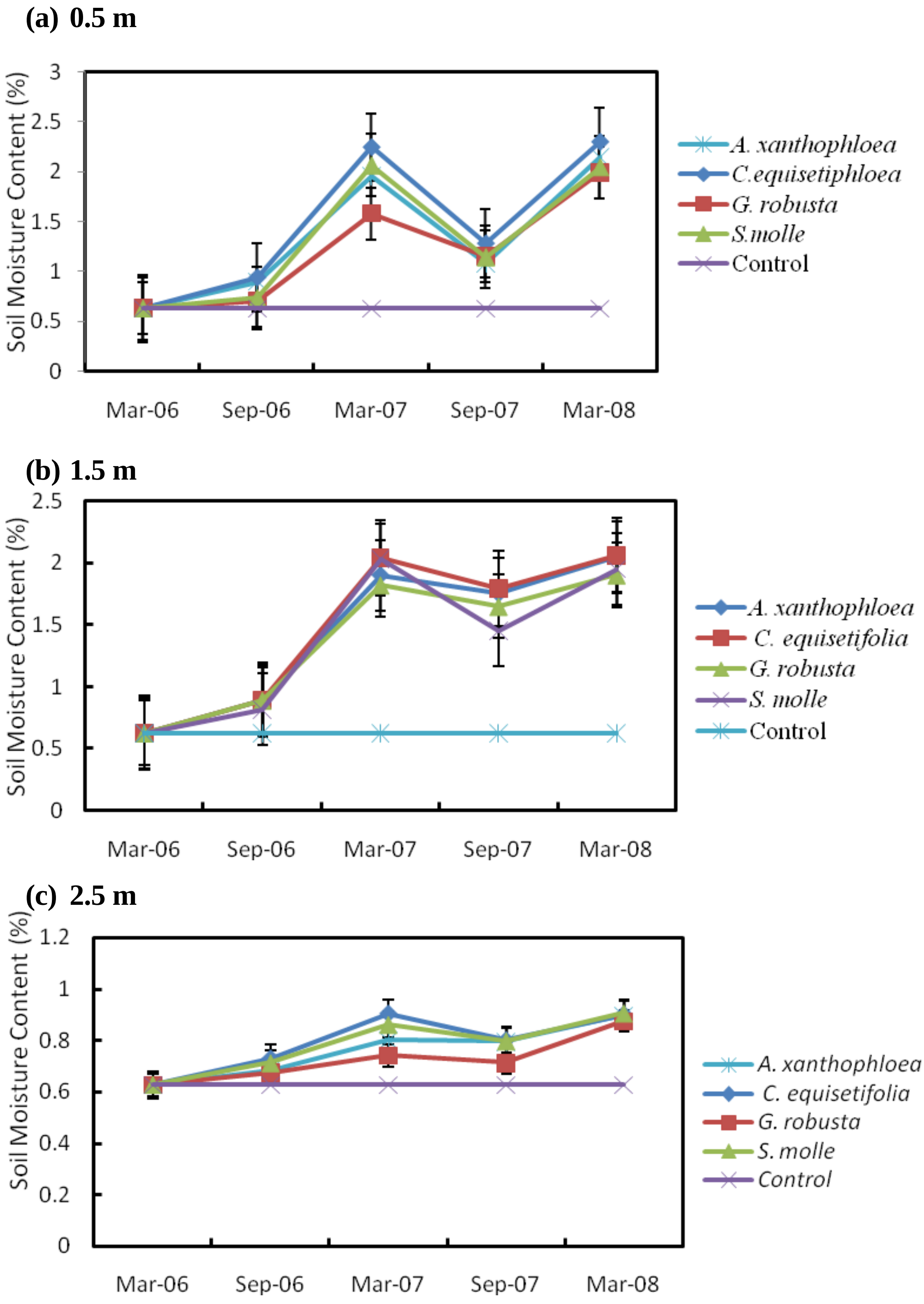


Figure 4.5 Timecourses of Soil Moisture Content (%), under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, within the 0 – 15cm horizon at (a) 0.5 m (b) 1.5 m and (c) 2.5 m from the tree rows. Vertical bars show SED values for comparing treatments.

It was also observed that soil moisture content was slightly lower at 0.5 m from the tree row before increasing slightly beyond 1.5 m and then decreased with further increase in distance, although these trends were not statistically significant (Figure 4.6).

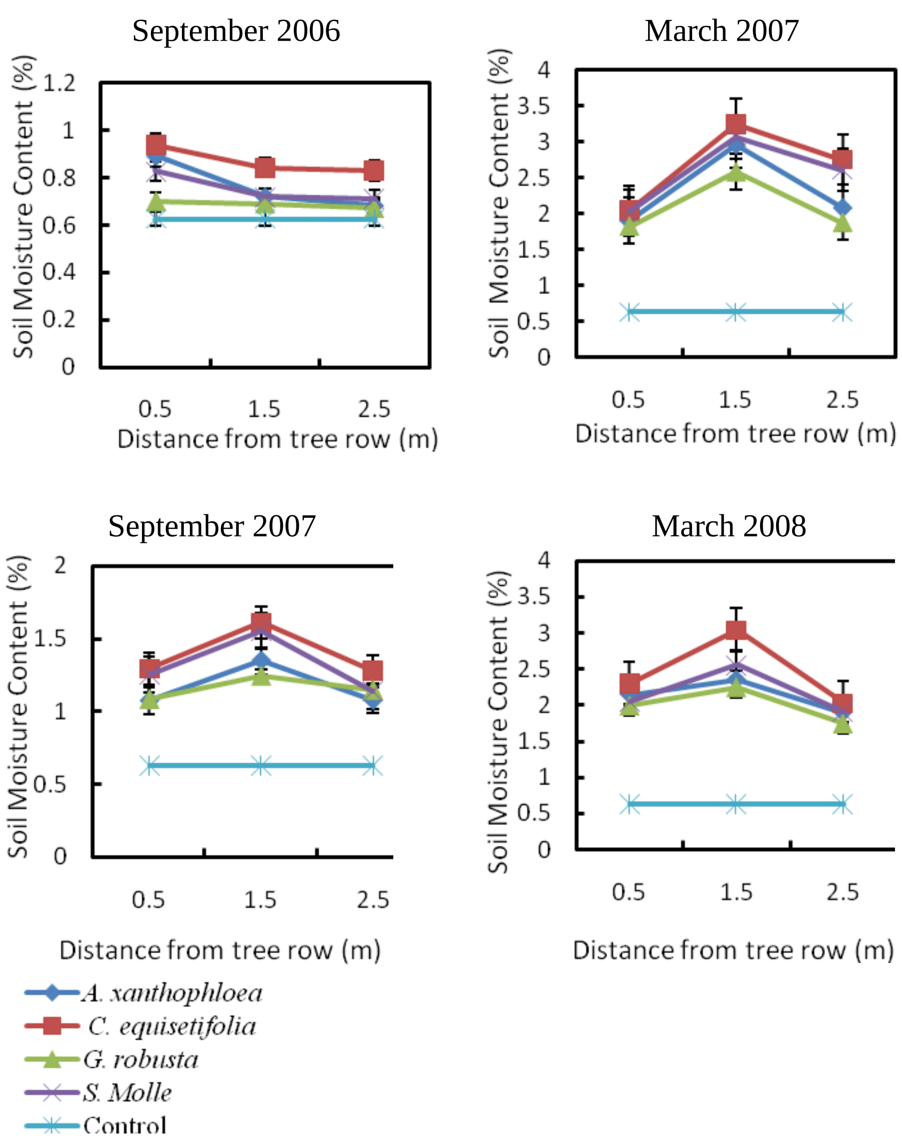


Figure 4.6 Soil Moisture Content (%) within the 0 - 15 cm horizon under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, for September 2006, March 2007, September 2007 and March 2008. Vertical bars show SED values for comparing treatments.

For the 0 – 5 cm, 15 – 30 cm and 30 – 45 cm soil horizons at a distance of 0.5 m from the tree rows, there were no significant differences detected between sampling depths or treatments, although the soil moisture content for the upper layer (0-15 cm) was consistently higher than that of the lower 15 - 30 cm and 30 - 45 cm horizon (Figure 4.7). However, all the soil values recorded under all the tree species were higher than the control values.

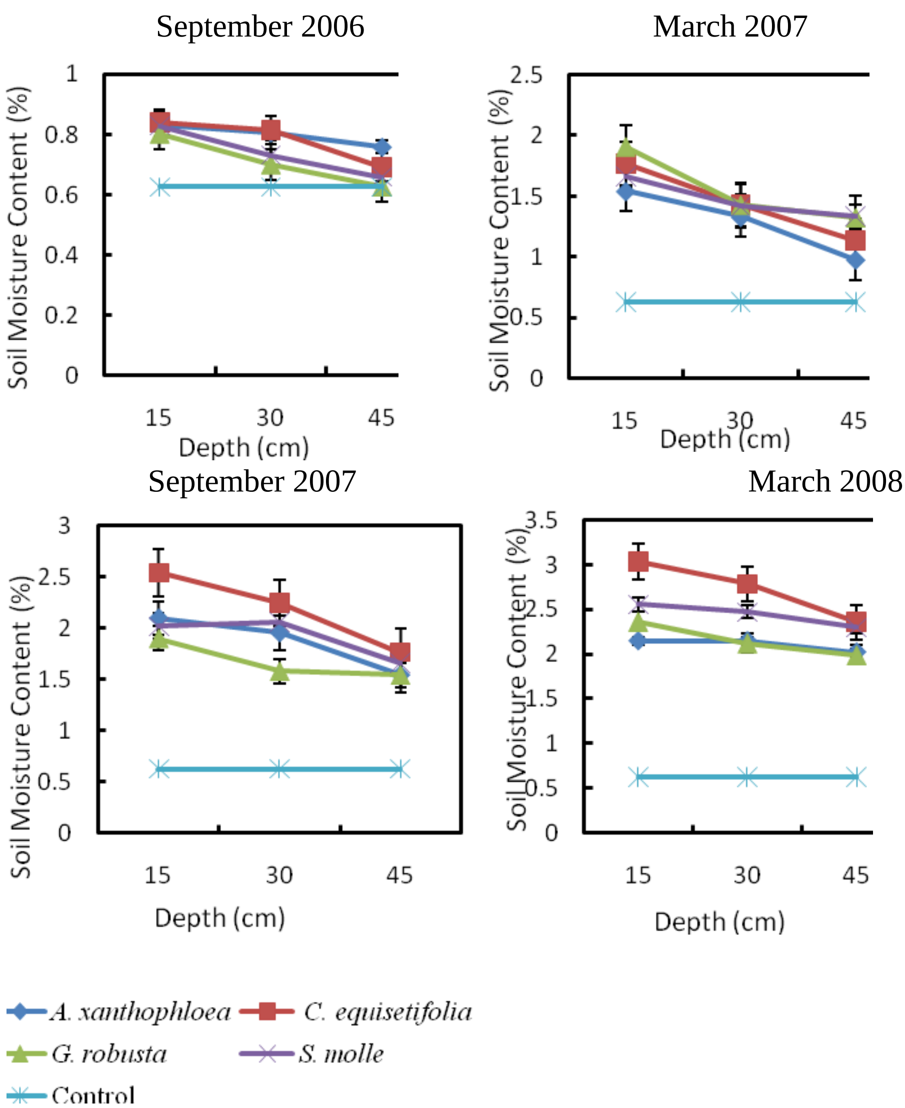


Figure 4.7 Profile for Soil Moisture Content (%) in the *A. xanthophloea*, *C. equisetifolia G. robusta* and *S. molle* treatments, at a distance of 0.5 m from the tree row, for September 2006, March 2007, September 2007 and March 2008. Vertical bars, show SED values for comparing treatments.

Soil moisture content is highly variable in both time and space, changing markedly after each rainfall event. The soil moisture content increase in March 2007 was due to the combined effects of precipitation and reduced potential evaporation. The decrease in September 2007 reflected the low rainfall (Figure 4.4) and increased potential evaporation at this time. Periods of high soil moisture were generally accompanied by increased tree growth (Figures 4.1). A similar pattern has been observed at Machakos in semi-arid Kenya (Howard, 1997; Lott, 1998; Mulatya, 2000) and in Uganda (Okorio, 2000).

Soil moisture content is an important property of soils, influencing soil solution chemistry and nutrient uptake by plants. Hence, moisture fluctuations regulate the availability of nutrients (Aguila, 2007). Trees are able to affect soil properties because of their relatively long residence time, large biomass accumulation, and extensive perennial rooting system (Gajaseni and Gajaseni, 1999). Plants consume large amounts of water and water uptake by trees is considered to be the main determinant of soil water depletion in the adjacent soil volumes and hence the distribution and availability of soil water (Broadhead *et al.,* 2003; Radersma and Ong, 2004).

Although trees may increase soil moisture content by increasing ground cover and thereby reducing soil evaporation, or by accessing water in the deeper horizons and subsequently releasing it in the surface horizons through the process of hydraulic lift (Burgess *et al*., 1998; Jackson *et al*., 2000), they may also decrease soil moisture content through their own uptake and transpiration of the water (Broadhead, 2000).

Soil moisture content values were constantly lower in the soils collected from under *G. robusta* and higher under *C. equisetifolia* than in any other treatment throughout the observation period. This suggests that the patterns of water abstraction differed, between species, possibly reflecting differences in rooting patterns between the various tree species examined (Zhang, 1996), although measurements of rooting depth and density were not made in the present study. Livesley (1999) reported that abstraction of water by *G. robusta* was greater from the surface horizons of the soil profile than from deeper horizons. Although the current study did not examine water uptake from deeper horizons, the results suggest that *G. robusta* probably extracted water from within the 0 - 15 cm soil profile since the values were lower than in any other treatment.

The decrease of the soil moisture content at 0.5 m from the tree row and then increasing slightly beyond 1.5 m and then decreasing with further increase in distance (Figure 4.5), suggested that the activity of tree roots declined with distance from the trees and that the main factor controlling soil moisture at distances exceeding 2.5 m from the tree row may have been soil evaporation. The higher values recorded at 1.5 m were probably due to shading effect. The soil moisture content of the upper layer was higher than that of the lower horizon (Figure 4.6). This pattern suggests that moisture tends to be concentrated in the topsoil layer, attributable probably to the relatively higher level of organic matter.

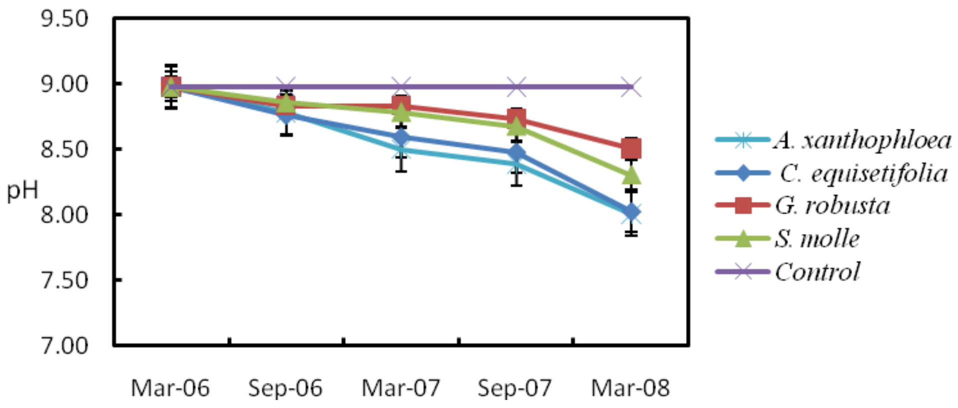
4.5 The influence of Tree species on Soil Chemical Properties

Chemical analysis carried out during the present study revealed particular significant effects in soil chemical attributes.

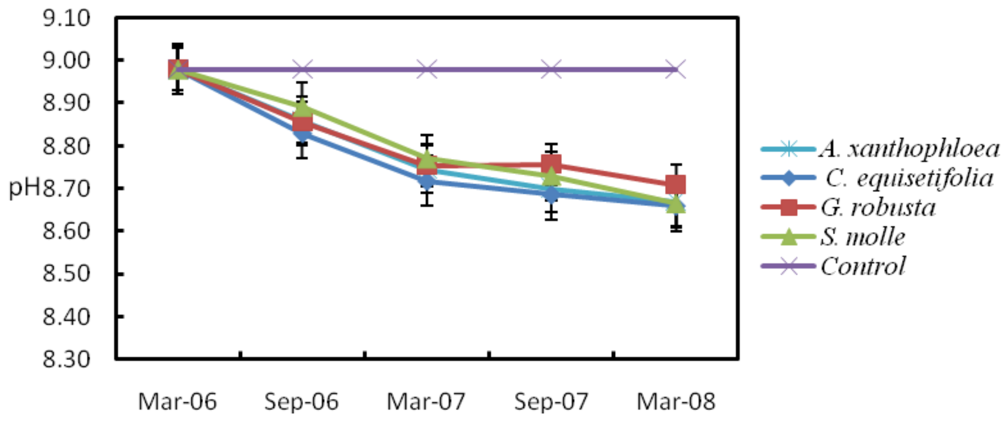
4.5.1 Soil pH

By the end of the observation period at 0.5 m from the tree line and 0 – 15 cm horizon the pH value in soils under *A. xanthophloea* had reduced from 8.98 to 8.00; for *C. equisetifolia* from 8.98 to 8.03; *S. molle* from 8.98 to 8.31 and *G. robust* from from 8.98 to 8.54 (Figure 4.8). A species effect on pH was apparent ($p<0.01$), with values being relatively lower in soils under *A. xanthophloea* (8.0) and *C. equisetifolia* (8.03) but ralatively higher under *S. molle*,(8.31) and *G. robusta* (8.51). The species-distance interaction was not significant but the pH values were relatively lower in soils close to the tree row (0.5 m) and increased with distance from the trees.

(a) 0.5 m



(b) 1.5 m



(c) 2.5 m

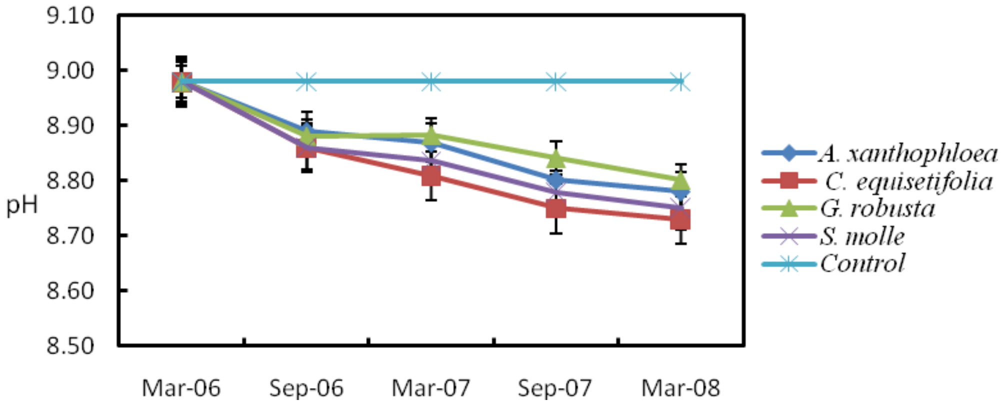


Figure 4.8 Timecourses of Soil pH for 0 – 15 cm horizon under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, at a distance of (a) 0.5 m (b) 1.5 m and (c) 2.5 m from tree rows. Vertical bars show SED values for comparing treatments.

Mean soil pH for all horizon (0–15, 15 –30, 30–45 cm), did not vary significantly between species but was lower in the upper horizon and again showed similar trends, under *A. xanthophloea* and *C. quisetifolia* which recorded lower pH values than pH values under *G. robusta* and *S. molle* (Figure 4.9).

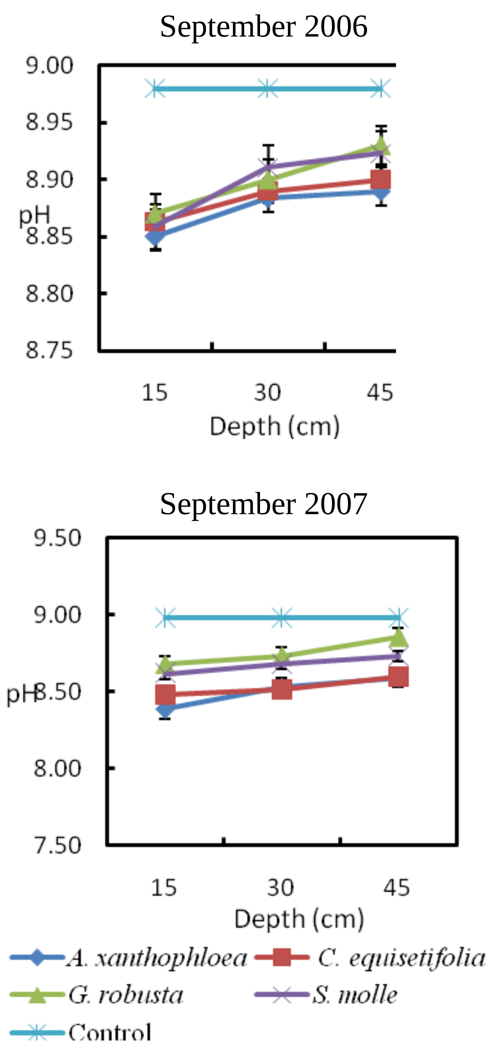


Figure 4.9 Profile for Soil pH in the *A. xanthophloea, C. equisetifolia G. robusta* and *S. molle* treatments, at a distance of 0.5 m from the tree row, for September 2006, March 2007, September 2007 and March 2008. Vertical bars, show SED values for comparing treatments.

The soil pH values were high in the soils samples collected from under all the tree species for most of the observation period, ranging between, 8.0 to 8.98 but were constantly lower than in the control treatment (8.98). This is in line with the high pH values in calcarious soils (Ruthrof, 1997), which cause a different nutritional environment for plant growth compared with non-calcareous soils. Munshower, (1994) noted that at an alkaline pH of 8.0, problems may arise for plant growth with the decreased availability of some nutrients. The relatively lower pH values recorded in the soils collected from under *A. xanthophloea* and *C. equisetifolia,* than under the other tree species suggest that the presence of trees may have had a moderate acidifying effect on soils close to the trees, which may be attributable to the formation of organic acids and release of carbon dioxide due to litter decomposition. Since, *A. xanthophloea* and *C. equisetifolia*, are leguminous trees, they would predominantly accumulate more nutrients within their biomass than *G. robusta* and *S. molle.* This would probably result in better growth and hence an increase in soil organic matter. Greater nitrification rates and nitrate leaching have also been reported to contribute to reductions in soil pH, as both processes may cause acidification (Ridley *et al.*, 1999; Schroth, 1999; Chang *et al.*, 2002). The significant difference in soil pH under the various tree species examined may also indicate that the decomposition rates of their litter differ, as the addition of organic matter is known to reduce soil pH (Landon 1991; Kumar, Hegde and Babu, 2000). The result obtained may suggest that the organic matter from *A. xanthophloea* is probably more easily decomposed than that from *G. robusta* and *S. molle.*

4.5.2 Soil Organic Matter

During the final observation, soils collected at 0.5 m from the tree row and at 0 – 15 cm horizon from under *C. equisetifolia* recorded relatively the highest organic matter content (0.38%). This was followed by *A. xanthophloea* (0.36%), *S. molle* (0.29%) and *G. robusta* (0.24%). The organic matter generally increased with time but remained constant in the control. Mean soil organic matter values throughout the observation period, under all the tree species were generally low ranging from 0.05% to 0.38%, as compared to tropical soils with limits of 2% for soil fertility (Landon 1991). The species-distance interaction was significant ($p<0.01$) with organic matter values being relatively higher in soils collected close to the tree row (0.5 m) and decreasing with distance from the trees (Figure 4.10).

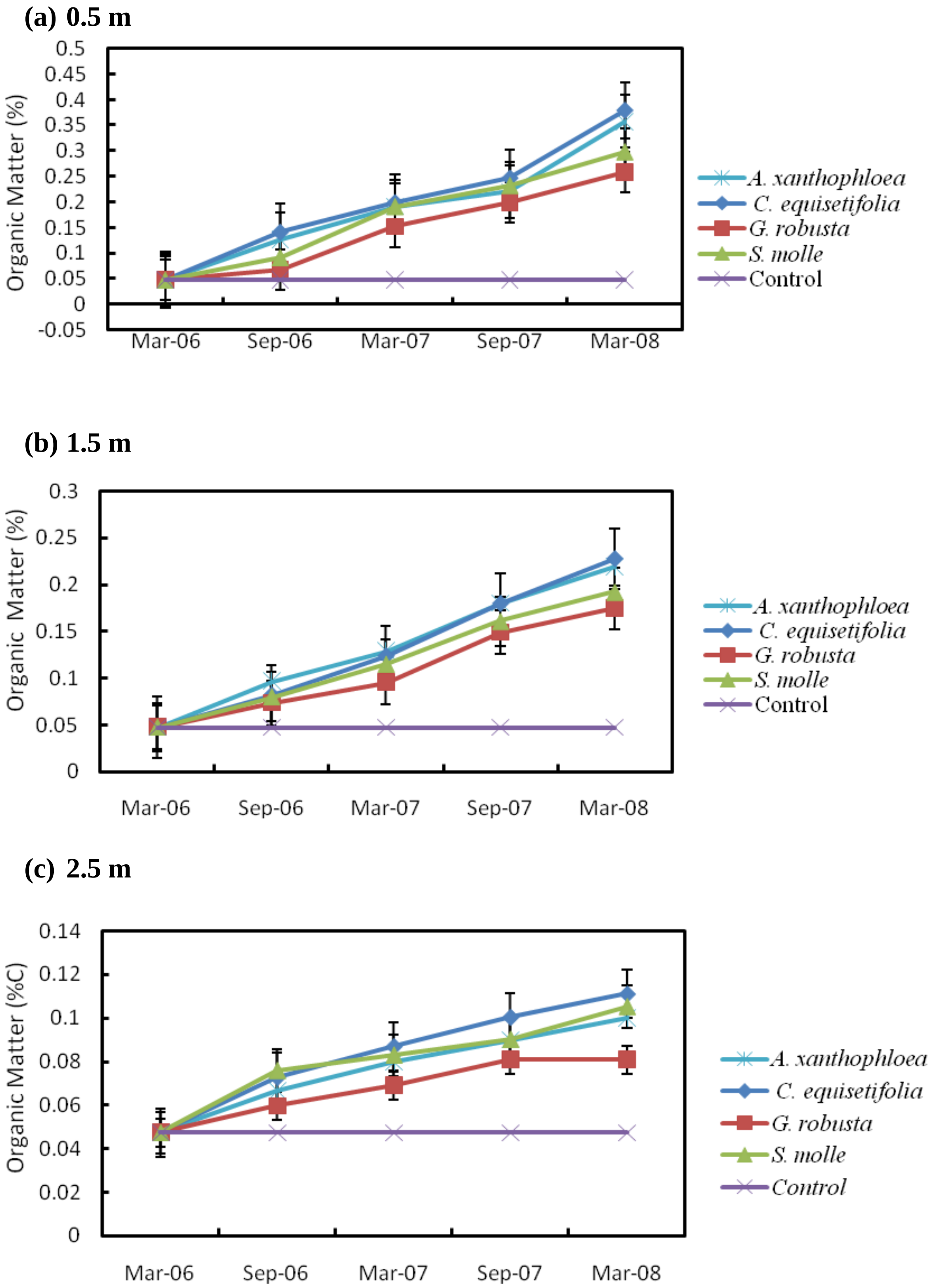
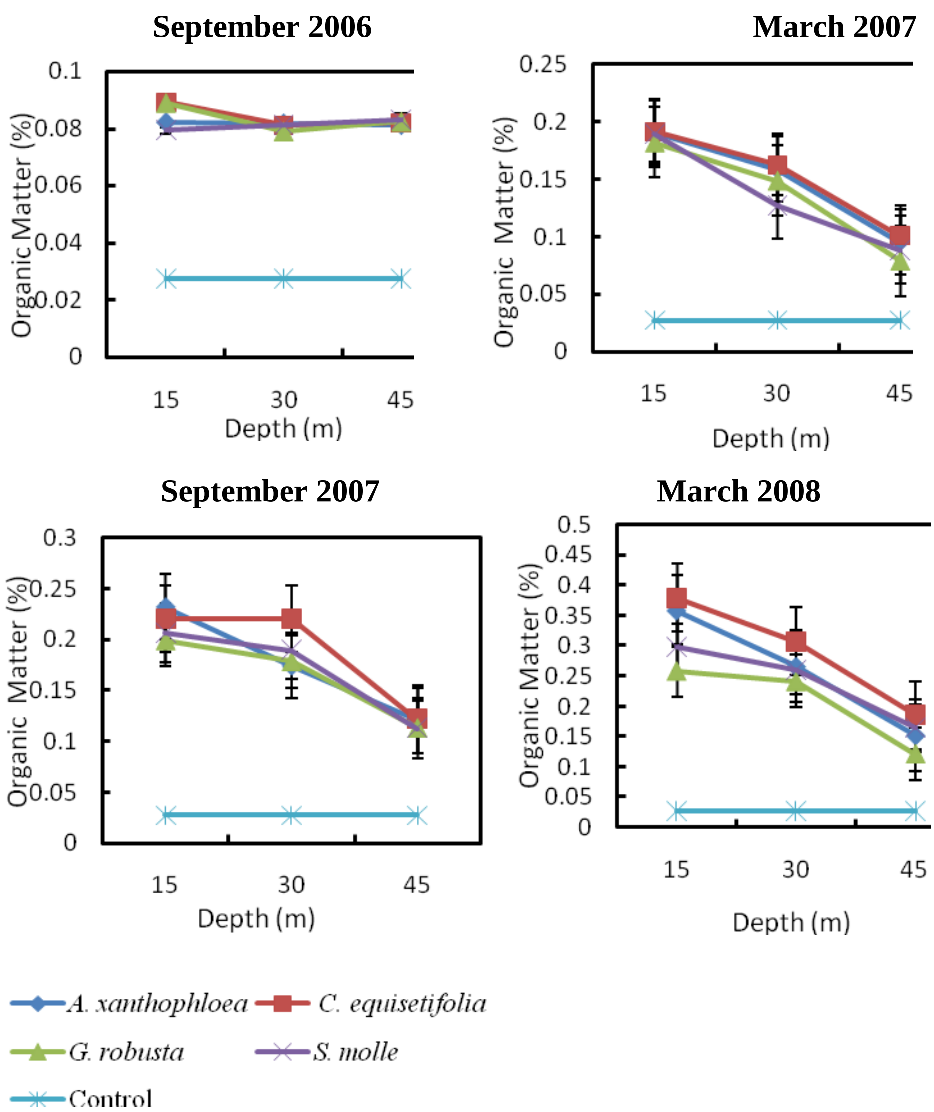


Figure 4.10 Timecourses of Soil Oganic Matter content (%) for 0 – 15cm horizon under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, at a distance of (a) 0.5 m (b) 1.5 m and (c) 2.5 m from tree rows. Vertical bars show SED values for comparing treatments.

Soil organic matter content for all horizons (0 –15 cm, 15 – 30 cm, 30 – 45 cm), at 0.5m from the tree rows did not vary significantly between species but was higher in the upper horizon (0 - 15 cm) than the lower horizons and again showed similar trends, under *A. xanthophloea* and *C. quisetifolia* which recorded higher organic matter values than values under *G. robusta* and *S. molle* (Figure 4.11).



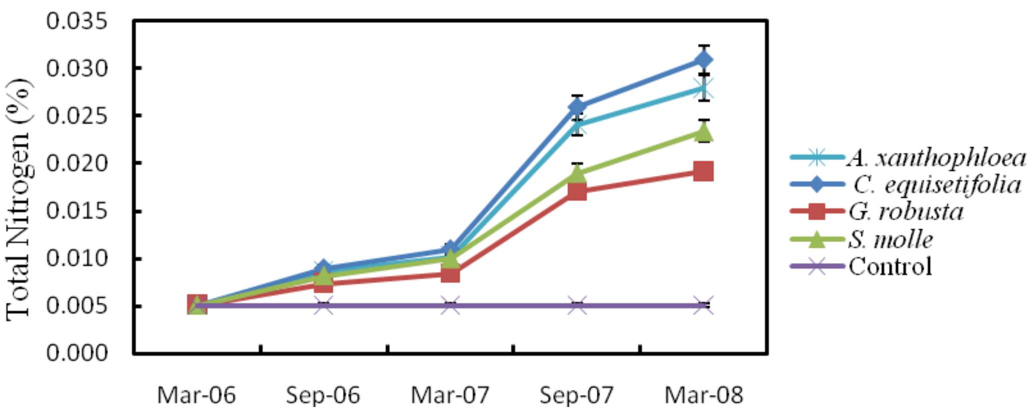
F
igure 4.11 Profile for soil organic matter (%), in the *A. xanthophloea, C. equisetifolia G. robusta* and *S. molle* treatments, at a distance of 0.5 m from the tree row, for September 2006, March 2007, September 2007 and March 2008. Vertical bars show SED values for comparing treatments.

The absence of beneficial soil chemical changes in the present study may be attributed to the small quantity of litter produced by the trees. Low soil organic matter content might also be explained by microbial activities in the rhizosphere utilizing the organic carbon, while the decaying root hairs might have enhanced the organic matter content in the soils around the trees. In the study area soil organic matter ranged from 0.05% to 0.38%. These levels were very low. For tropical soils, a level below 2% is regarded as a low concentration of organic carbon (Landon 1991). All the species had a noticeable influence on soil organic matter content, which decreased with distance from the tree row (Figure 4.10). This trend is likely to have reflected the greater leaf fall from trees received at positions close to the tree row compared to those further from the trees. Trees have previously been shown to increase soil organic matter content through a combination of leaves and other litter lost from the tree crowns and decomposition of roots (Nambiar, 1983; and Haggar *et al.,* 1993). Kang (1997) also concluded that organic matter content in the surface horizons was a function of litter quantity and quality, while Balasubramanian and Sekayange (1991) showed that the positive impact of trees on soil fertility was largely determined by the quantity of tree biomass produced. In the present study, soil organic matter content was relatively higher under *A. xanthophloea*, *C. equisetifolia* and *S. molle.* This probably reflected greater leaf fall and other litter lost from the tree crown as compared to *G. robusta.*

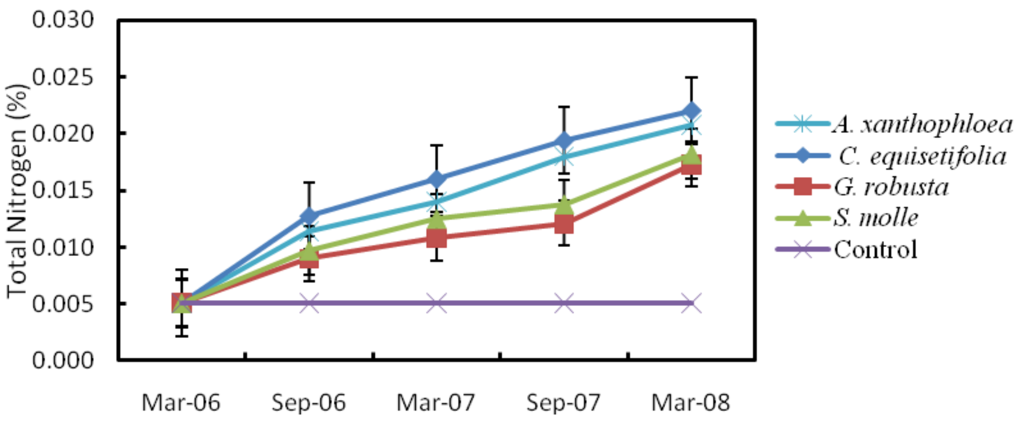
4.5.3 Soil Total Nitrogen

Soil total Nitrogen values recorded were < 0.03% under all tree species by the end of the observation period. A species effect on Nitrogen was significant ($p<0.01$), with the soils collected from under *C. equisetifolia* from 0-15 cm horizon and at 0.5 m from the tree row recording relatively the highest levels of total Nitrogen (0.031%), (Figure 4.12). This was followed by *A. xanthophloea* (0.028%). The Nitrogen values were substantially lower under *S. molle* and *G. robust* (0.023 % and 0.019 % respectively).

(a) 0.5 m



(b) 1.5 m



(c) 2.5 m

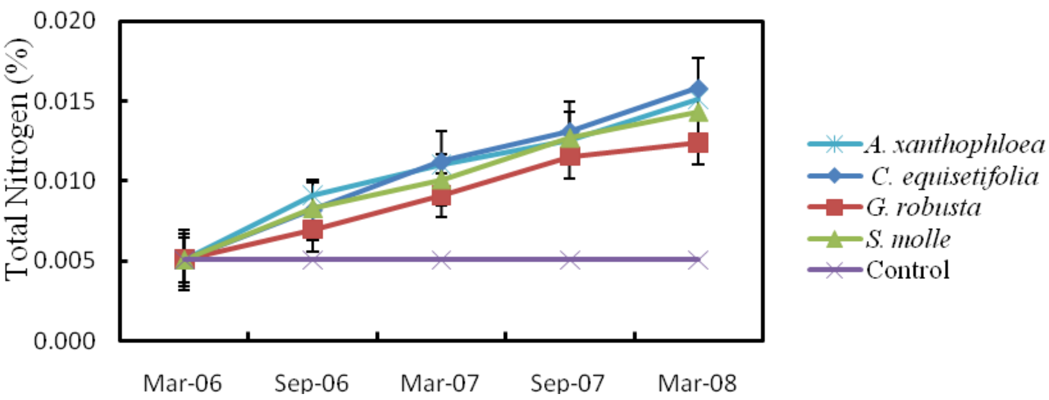


Figure 4.12 Timecourses of Soil Total Nitrogen (%) content for 0 – 15cm horizon under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, at a distance of (a) 0.5 m (b) 1.5 m and (c) 2.5 m from tree rows. Vertical bars show SED values for comparing treatments.

Figures 4.13 show soil total Nitrogen content for the 0 -15 cm, 15 – 30 cm and 30 – 45 cm horizons, at a distance of 0.5 m from the tree rows. No significant differences were detected between sampling depth or treatments, although the values of the upper layer (0–15 cm) were consistently higher than those of the lower 15–30 cm and 30 – 45 cm horizon.

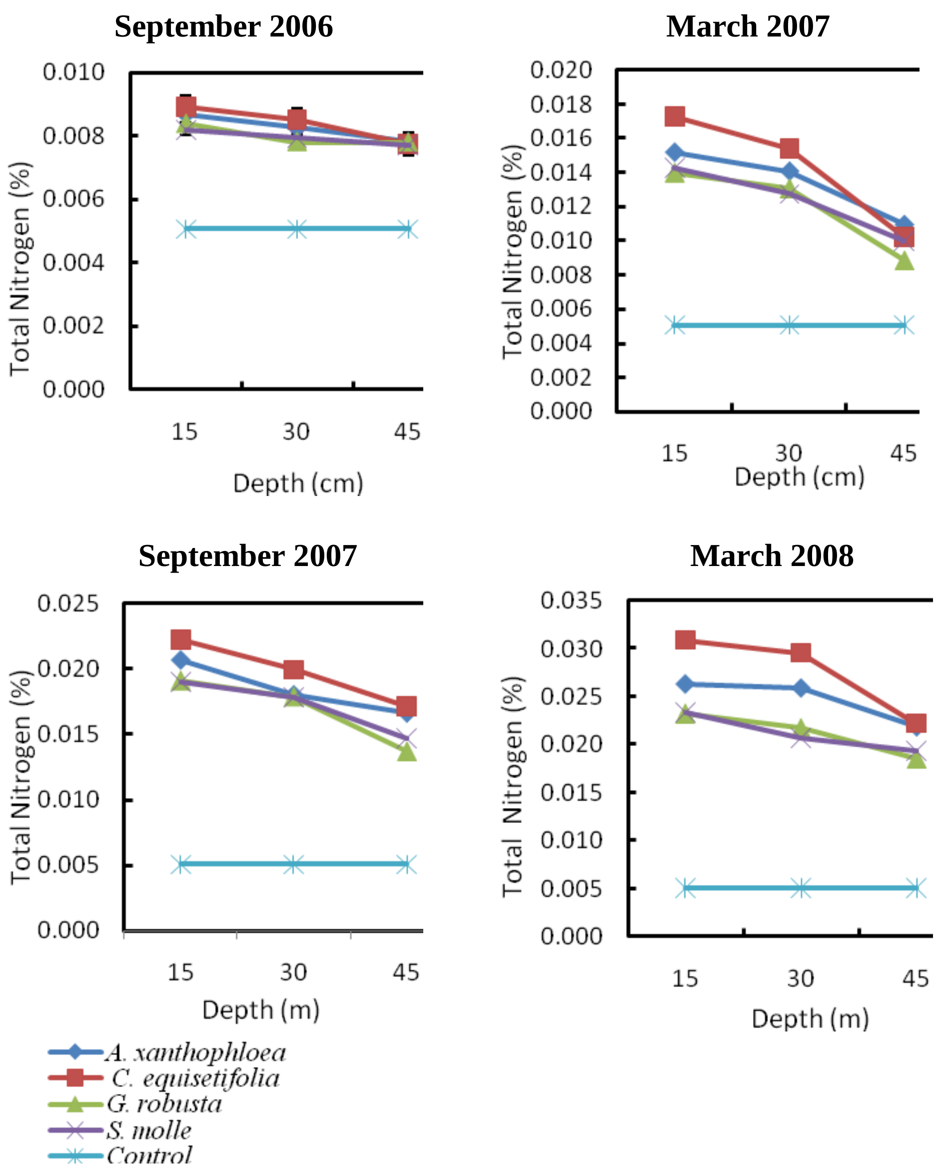


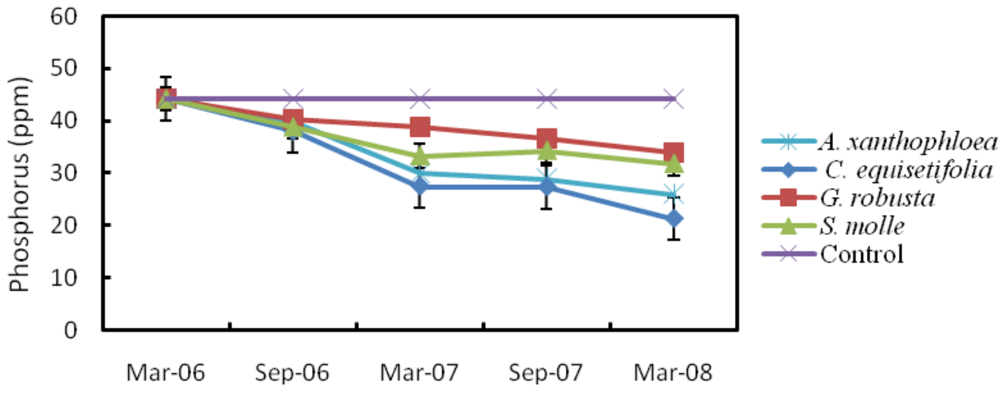
Figure 4.13 Profile for Soil Total Nitrogen (%), in the *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle* treatments, at a distance of 0.5 m from the tree row, for September 2006, March 2007, September 2007 and March 2008. Vertical bars, show SED values for comparing treatments.

All the soil total Nitrogen values recorded throughout the observation period (ranging from merely 0.005% to 0.031%), were below the 0.2% threshold construed as adequate for tropical soils (Lal and Stewart, 1992), which demonstrated that soil fertility was low. The low levels of Nitrogen recorded can also be related to the soils' low store of organic carbon. The total Nitrogen content of soil depends on the balance between the demand imposed by plants and the mechanisms of nutrient supply (Staff and Berg, 1982). Levels of Nitrogen were relatively lower in soils under *S. molle* and *G. robusta* (0.023 % and 0.019 % respectively), these low values may be related to the greater competition for uptake, and may also reflect the demand for nitrogen to support the microbial activity involved in litter decomposition (Anyango, 2005). The addition of leaf litter increases soil organic content, which might have induced rapid proliferation of microbial populations (Kumar, Hegde and Babu, 2000). The relatively higher values of Nitrogen recorded for soils under *A. xanthophloea* and *C. equisetifolia* could be due to the fact that these tree species are leguminous and have nitrogen-fixing capability. Mycorrhizas and cluster roots may be important components in Nitrogen acquisition, supplementing Nitrogen fixation as well as enabling uptake of other nutrients, as well as water (Sprent, 1995). However, it appears that these processes had not yet significantly affected soil Nitrogen status in the present study, probably due to the short period of this study.

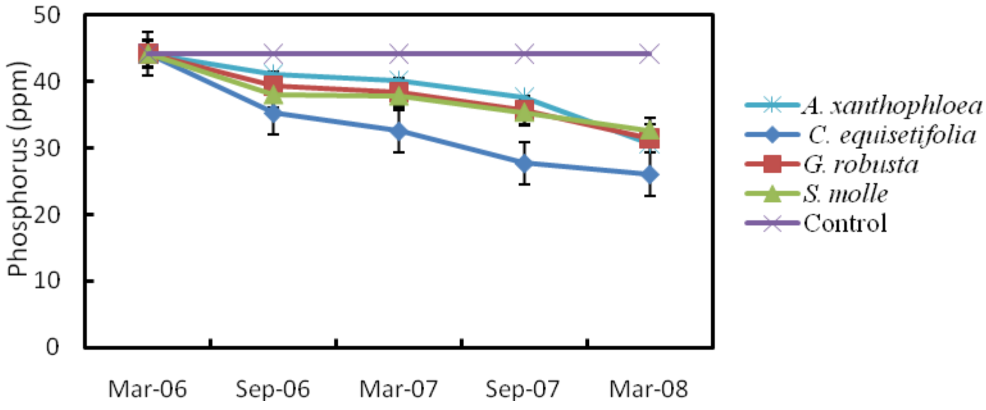
4.5.4 Soil Total Phosphorus

Soil Phosphorus concentrations were moderate ranging from 44.15 ppm to 21.33 ppm. Although not significant, by the end of the observation period, soils Phosphorus was lower in the soils collected from under *A. xanthophloea* (25.97 ppm) and *C. equisetifolia* (21.33 ppm) than those from under *G. robusta* (33.89 ppm) and *S. molle* (31.80 ppm) and the values were relatively lower close to the tree row (0.5 m) and increased with distance from the trees (Figure 4.14).

(a) 0.5 m



(b) 1.5 m



(c) 2.5 m

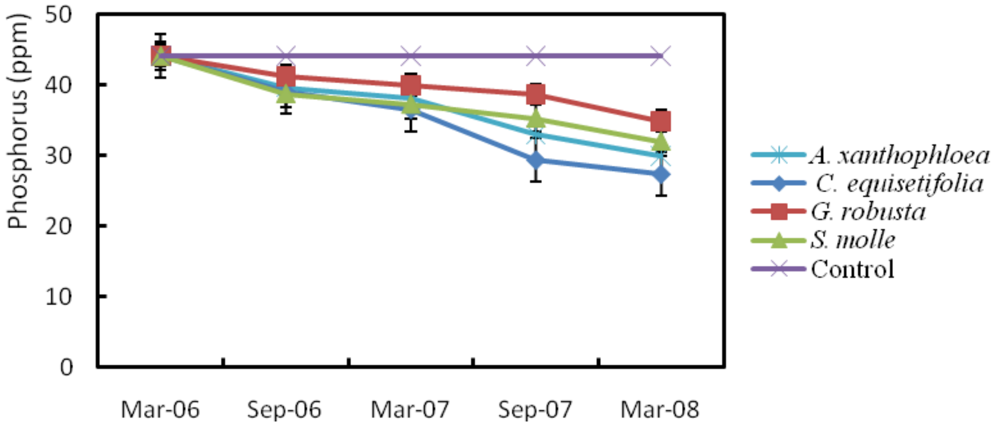


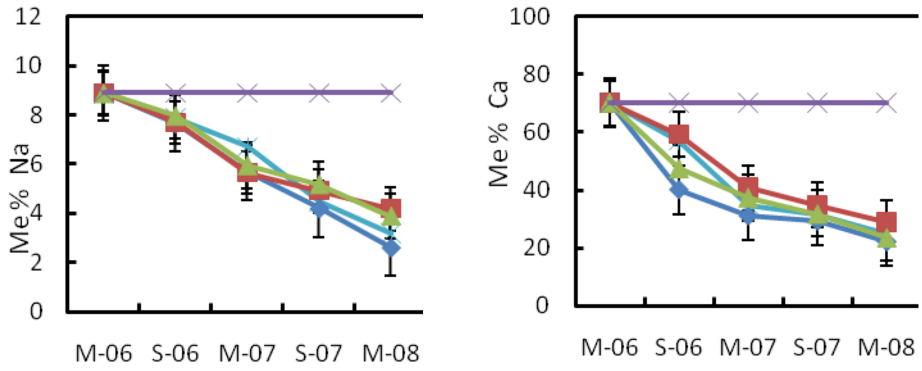
Figure 4.14 Timecourses of Soil Phosphorus (ppm) content for 0 – 15cm horizon under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, at a distance of (a) 0.5 m (b) 1.5 m and (c) 2.5 m from tree rows. Vertical bars show SED values for comparing treatments.

Soil total Phosphorus concentration was not significantly affected by tree species, indicating the absence of any negative or positive influences of tree species imposed. However, by the end of the observation period, soils Phosphorus was lower in the soils collected from under *A. xanthophloea* and *C. equisetifolia* than those from under *G. robusta* and *S. molle,* as seen in Figure 4.14. These differences can be explained by the observed difference in soil pH between the species, since pH is known to influence the status and availability of soil Phosphorus (Haggar *et al*., 1991; Hands *et al*., 1995).

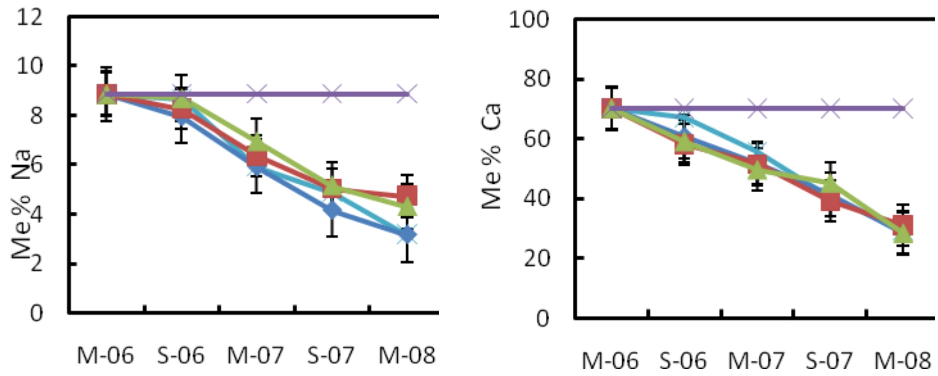
4.5.5 Soil Exchangeable Cations

The soil concentrations of exchangeable calcium ranged from 70.13 to 22.17 me %, sodium ranged from 88.89 to 2.59 me % and magnesium from 8.43 me % to 3.42 me %, whereas that of potassium ranged from 3.66 to 1.54 me % (Figure 4.15 and Figure 4.16). No significant differences were detected between species or with distances from the tree row. However, at the end of the observation period, the soil concentration of all the exchangeable cations (Ca, Na, Mg and K) had decreased and the values were lowest close to the tree row (0.5 m) and increasing with distance from the trees.

(a) 0.5 m



(b) 1.5 m



(c) 2.5 m

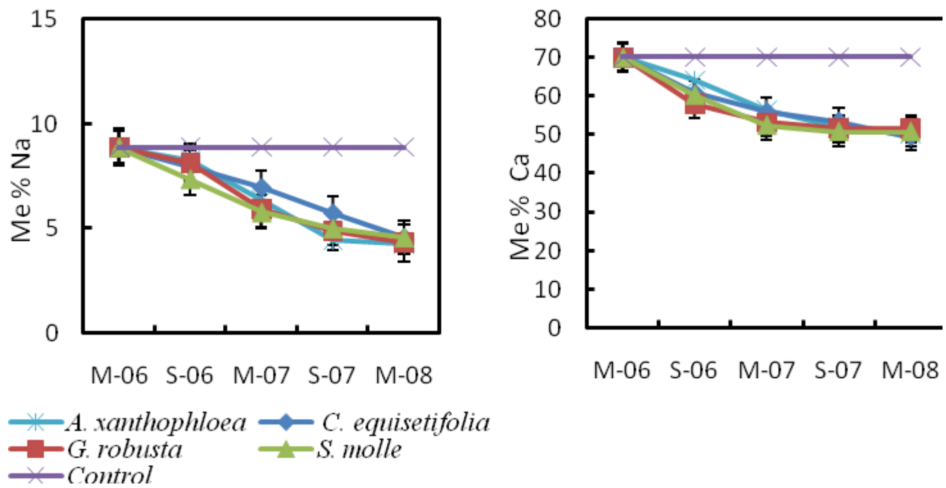


Figure 4.15 Timecourses of Soil Exchangeable Cations (Na and Ca) content (me %) for 0 – 15cm horizon under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, at a distance of (a) 0.5 m (b) 1.5 m and (c) 2.5 m from tree rows. Vertical bars show SED values for comparing treatments.

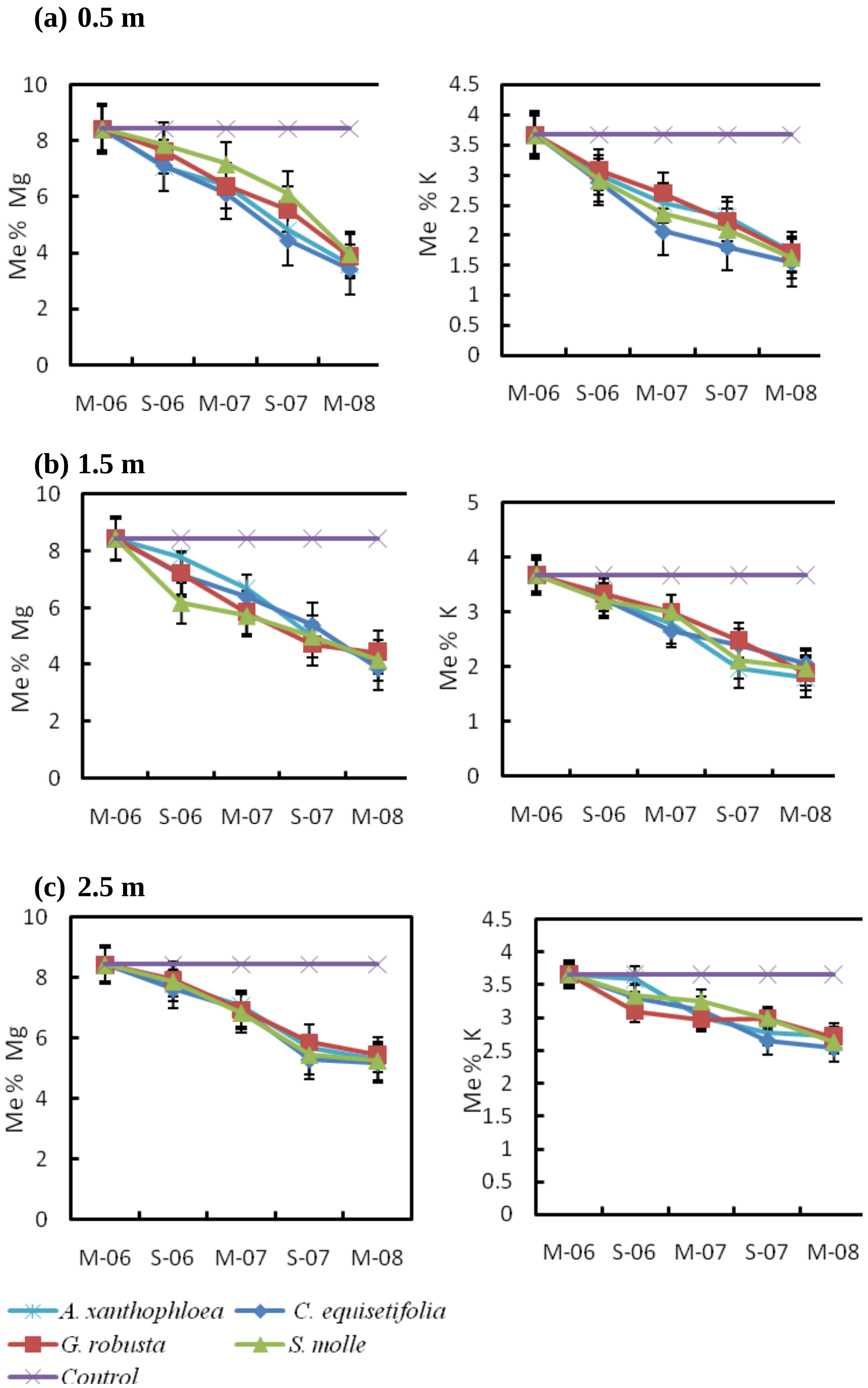


Figure 4.16 Timecourses of Soil Exchangeable Cations (Mg and K) content (me %) for 0 – 15cm horizon under *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, at a distance of (a) 0.5 m (b) 1.5 m and (c) 2.5 m from tree rows. Vertical bars show SED values for comparing treatments.

Trees tend to be more sensitive to magnesium deficiency, however, the level for both exchangeable magnesium and sodium were adequate. The soil exchangeable cations (Ca, Na, Mg and K) had decreased by the end of the observation period and the values were lowest in the soils collected close to the tree row (0.5 m) increasing with distance from the trees. This trend suggested that the effects of activity of tree roots declined with distance from the trees. As was also found in other studies, with time, and under cropping, the exchangeable cations especially of calcium and magnesium decreased and exchangeable acidity increased (Juo *et al*., 1995; Smyth and Cassel, 1995). In most soils, Ca and Mg are more susceptible to leaching than potassium (Schroth and Lehmann, 2003). Potassium is usually leached in much smaller quantities. Hence, the high values recorded for Ca and Mg.

Soil improvement is important in habitat restoration of mining and related disturbed lands. The reconstitution and management of a suitable soil layer to support vegetation in the long run is a crucial phase of landscape rehabilitation (Smith and Sobek, 1978; Roberts and Roberts, 1986). The inadequacies in the soil components can frustrate revegetation attempts.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The main conclusions arising from the findings of the study are presented in the first section of this chapter while in the second section, recommendations are suggested on possible areas for future research and on the way forward.

5.2 Conclusion

The present study examined the performance of four tree species; *A. xanthophloea*, *C. equisetifolia*, *G. robusta* and *S. molle*, with the aim of evaluating their suitability for adoption in the rehabilitation of limestone quarry areas.

It was observed that the mine waste used to backfill the quarry was not suitable for plant growth. This was evident in the soil analysis recorded before tree planting which showed that the study area had, on average, high pH values (8.98), low organic matter content (0.047%), low total nitrogen (0.005%) and low soil moisture content (0.626 %).

All the tree species had a noticeable influence on soil physical and chemical properties. The pH values and total Phosphorus were relatively lower in soils close to the tree rows (0.5 m) and increased with distance from the trees, while the soil values for soil moisture, organic matter, total Nitrogen, and exchangeable cations were relatively higher close to the tree rows (0.5 m) and decreased with distance from the trees.

It was also observed that the soil properties under *C. equisetifolia* at 0.5 m from the tree row and for the 0 – 15 cm horizon, improved significantly. This was followed by *A. xanthophloea and S. molle,* but for *G. robusta* there was no significant change. Soil organic matter for *C. equisetifolia* increased from 0.047 % to 0.38 %; soil total Nitrogen from 0.005 % to 0.031 %; and soil moisture content from 0.63 % to 2.3 %, while the pH, was lowered from 8.98 to 8.00.

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 both these species have the ability to enrich the soil through their nitrogen-fixing activity offers an added advantage. 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.

5.3 Recommendations and Future Research

The present study has shown that some issues require further consideration:

5.3.1 Recommendations

- Growth increment and growth rates of the tree height, basal stem diameter and diameter at breast height alone may not give a reliable estimate of above ground plant growth. Other non-destructive measurements, like growth of secondary branches or branching pattern, should be taken into account in future measurements. Some plants could also invest in the production of a higher proportion of below ground biomass, which was not assessed in this study.

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

- 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 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.

- Research by different institutions in various regions should be better coordinated and integrated and Research institutions should develop a stronger linkage with miners who have the mandate to execute restoration, so that, more pertinent topics can be addressed in the research such as ecological, economic and social considerations. These studies call for more financial, infrastructural and logistical support from the government.

- Finally, perhaps a simply good cure to the present low rehabilitation rate of mine lands as a whole is to ensure strict observation of the relevant laws and regulations. Although in Kenya, restoration is legally bound with the mining activities (Environmental Management and Coordination Act, 1999), the overall restoration rate is very low due to the weak enforcement of the relevant laws and regulations.

5.3.2 Future Research

- The present study examined the performance of only four tree species for the rehabilitation of the limestone quarries in semi-arid areas. Similar experiments should be conducted with other native and exotic tree species, because increasing the number of plant species would create an array of microsite conditions for colonization by other species and also mimic the natural vegetation, and accelerate secondary succession.

- The database on which the rehabilitation study was validated was limited. Future research to detail nodulation status, nitrogen fixation rates, physiological (e.g. stomatal conductance and photosynthetic activity) adaptations, morphological characteristics (e.g. canopy size, leaf area and leaf flushing and fall) and genetic diversity in both legumes and actinorhizal trees will provide fundamental knowledge for further conservation and utilisation of these plants.

- Many studies have demonstrated large differences in the effects of tree species on soils (Binkley, 1996; Binkley and Giardina, 1998). The mechanism behind these effects remains poorly known, including the importance of differences in below ground carbon allocation and the effects of tree species on soil organisms that mediate biochemical cycles.

- Further research on plant responses to water stress and the adaptability of species in arid and semi-arid environments is increasingly important because water supply is the major limiting factor in these areas hence this aspect deserves further study for a longer period.

REFERENCES

Abdul-Kareen, A.W. and McRae. S.G. (1984). The effects on topsoil of long term storage in stockpiles. **Abulfatih H. A. and Hashish, A. (1995).** “A contribution of Acacia Species to *Plant and Soil* 76, 357-363.

Aggregate Research. (2010). aggregate research.com Feb, 26 2010. 20 feared killed in granite landslide. http://www.hindustantimes.com

Agricola, G. (1556). De re Metallica, Book II. Translated from the Latin by Hoover, H.C and Hoover, L. H.

Aguila, A. E. (2007). Soil Fertility in calcareous Tropical Soils from Yucatan, Mexico, and Villa Clara, Cuba, affected by Land use and Soil Moisture effects. pp78. Cuvillier Verlag. ISBN 3867271437.

Akech, A.C. (1987). *A Taxonomic Study of the Acacia Grains in Kenya. MSc Thesis.* University of Nairobi.

Akinrinde, E.A. (2004). Soils: Nature, Fertility, Conservation and Management. AMS Publishing, Inc. Vienna, Austria.

Aluanga, L. (2010). “Abandoned quarry now waste eyesore”. The Standard, Saturday 19 June, 2010.

Anderson, J.M., Ingram, J.S. (1993). *Tropical soil biology and fertility: handbook of Methods.* CAB International, Wallingford, UK, pp 221.

Andrews, W. H. and Bauder, W.W. (1968). The Effects of Industrialization on a Rural Country: A comparison of social change in Monroe and Noble countries of Ohio department series 407. Wooster, Ohio Agricultural research and Development Center.

Anud, B.S. (2008). Casuarina, a Salt tolerant, Drought resistant tree for converting unfertile lands to fertile lands. http://www.lankanewspapers.com/news/2008/5/28015_space.html

Anyango, S.O. (2005). *Sustainability of Dryland Afroforestry Systems in Eastern Kenya: Farmers' perceptions, Physio-Ecological Factors and Landscape Patterns*. PhD Theses, Kenyatta University, Kenya. pp. 166.

APCM, (1977). Associated Portland Cement Manufacturers Limited, Geology Division. Kenya: East Afican Portland Cement Co. Ltd. Athi River Kunkur Reserves. Report No. GR/278/1977.

Ayoti, O. (2008). Bamburi Cement, first in Africa to receive the prestigious Wildlife Habitat Council certification - (Tuesday, January 20 2009): *EnviroConserve Africa*. A publication of Impulse Communication Options Ltd.

Bailey. D and Gunn. J. (1991). Land for Replication as an approach to the Reclamation of Limestone Quarries. A paper presented at the Third International Conference on Land Reclamation. An end to Dereliction? University of Wales, College of Cardiff. Cardiff. UK.

Balasubramanian and Sekayange (1991). Effects of tree legumes in hedgerows on soil fertility changes and crop performance in the semi-arid highlands of Rwanda. *Biological Agriculture and Horticulture,* 8: 17 – 32.

Bashour, I.I. and Sayegh, A.H. (2007) Methods of Analysis for Soils of Arid and Semi-Arid Regions. Food and Agriculture Organization of the United Nations, Rome.

Belsky, A.J., Amundson, R.G., Duxbury, J.M., Riha, S.J., Ali, A.R., and Mwonga, S.M. (1989). The effects of trees on their physical, chemical, and biological environments in a semi-arid savanna in Kenya. *J Appl Ecol* 26:1005–1024.

Binkley, D. (1996). The influence of tree species on forest soils – processes and patterns. In: Mead, D.J., Cornforth, I.S. (Eds.), Proceedings of the trees and soils workshop. Agronomy Society of New Zealand, Eds. Spec. Pub. 10, Lincoln University Press, Canterbury, pp, 229-234.

Binkley, D. and Giardina, C. (1998). Why do trees affect soils in temperate and tropical forests? The warp and woof of tree/soil interactions. *Biogeochemistry* 42, 89-106.

Blood, K. (2001), *Environmental weeds: a field guide for SE Australia*, Mt Waverley, Victoria, Australia: *CH Jerram*, pp. 36-37.

Bohn, H.L., McNeal, B.L. and O Connor, G.A. (2001). Soil Chemistry. 3rd edition. Published by John Wiley & Sons.

Boocock, C.N. (2002). *Environmental Impacts of Foreign Direct Investment in the Mining Sector in Sub-Saharan Africa.* OECD Global Forum on International Investment. Conference on Foreign Direct Investment and the Environment. Lessons to be Learned from the Mining Sector. 7 - 8 February 2002. pp 18.

Bradshaw A.D. (1990). The reclamation of derelict land and the ecology of ecosystems. In: Jordan W.R., Gilpin, M.E, Aber J.D, editors. *Restoration ecology*: a synthetic approach to ecological research. Cambridge University Press. pp. 53–74.

Bradshaw A.D. (1997). The reclamation of derelict land and the ecology of ecosystems. In: Jordan WR, Gilpin ME, Aber JD, editors. Restoration ecology: a synthetic approach to ecological research.

Bradshaw, A. D. and Chadwick, M. J. (1980). The restoration of land: the ecology and reclamation of derelict and degraded land. Blackwell, Scientific Publication. Oxford, England.

Bradshaw, A.D. (2000). The use of natural processes in reclamation—advantages and difficulties. Landscape Urban Plan 2000; 51:89–100.

Broadhead, J. (2000*).* *Ecophysiology of Indigenous Trees in Agroforestry Systems in the Semi-arid Tropics*. PhD thesis, University of Nottingham, UK, pp 259.

Broadhead, J., Ong C.K. and Black, C.R (2003). Tree phenology and water availability in semi-arid agroforestry systems in Kenya. *Forest Ecology and Management*, 180: 61-73.

Bui, E.N., Loeppert, R.H. and Wilding, L.P. (1990). Carbonate phases in calcareous soils of the western United States. *Soil Science Society*. *Am. J*. 34: 39 – 45.

Buresh R.J. and Tian G. (1997). Soil improvement by trees in sub-Saharan Africa. *Agroforestry Systems,* 38:51-76.

Burgess, S.S.O., Adams, M.A., Turner, N.C. and Ong, C.K., (1998). The Redistribution of soil water by tree root systems. *Oecologia,* 115:306-311.

Busuyi, A.T., Frederick, C. and Fatai, I.A. (2008). Assessment of the Socio-Economic Impacts of Quarrying and Processing of Limestone at Obajana, Nigeria. *European Journal of Social Sciences* – Volume 6, number 4 (2008).

Chang, S.X., Amatya, G., Beare, M.H., and Mead D.J. (2002). Soil properties under a *Pinus radiate* – ryegrass silvopastoral system in New Zealand. Part 1. Soil N and moisture availability, Soil C and tree growth. *Agroforestry Systems*, 54: 137 – 147.

Chaoji, A. (2009). Eco-Restoration Of Limestone Quarries. Case Study: Limestone quarries of Gujarat Ambuja Cement Ltd. Kodinar, INDIA. March 2, 2009. Pugmarks Ecologix.

Chege, A.M. (1982). Analytical Methods used at NAL and the Interpretation of the resultant data. “Internal Training Course for Kenya Soil Survey Staff, NAL, 21st June – 3rd July 1982.Soil Chemistry. National Agricultural Laboratories.

Clemente, A.S., Werner, C., Ma´guas, C., Cabral, M.S., Martins-Louc¸ M.A. and Correia, O. (2004). Restoration of a Limestone Quarry: Effect of Soil Amendments on the Establishment of Native Mediterranean *Sclerophyllous* Shrubs. *Restoration Ecology* Vol. 12 No. 1, pp. 20.

Clewell, A.F. and Aronson, J. (2007). Ecological Restoration: Principles, Values, and Structure of an Emerging Profession. Island Press, Washington, D.C.

Coe, M. and Beentje, H. (1991). A field guide to the Acacias of Kenya. Oxford University press

Cooke J.A.and Johnson M.S. (2002). Ecological restoration of land with particular reference to the mining of metals and industrial minerals: A review of theory and practice. *Environ. Rev.*, 10: 44-71.

Cullen, W.R, Wheater, C.P. and Dunleavy, P.J. (1998). A mycorrhizal survey of plants growing on mine wastes in southeast Spain. *Arid Soil Research and Rehabilitation* 8:59–68.

Dahl, N. (1996). *Casuarina equisetifolia*: its use and future in mine rehabilitation in Northern Australia. In *Recent Casuarina Research and Development.* Eds. K. Pinyopusarerk, J.W. Turnbull and S.J. Midgley. CSIRO, Canberra: 204-208.

Davies, T.C (1993). Mineral Development in Kenya. In: Geology for Sustainable Development.

Diem, H.G., Duhoux E, Zaid H, and Arahou M. (2000). Cluster roots in *Casuarinaceae*: role and relationship to soil nutrient factors. *Ann. Bot.*, 85: 929–936.

Dommergues, Y. R. (1995). Nitrogen fixation by trees in relation to soil nitrogen economy. *Fertilizer Research*, 42: 215-230.

Duan, W., Hai Ren, H., Fu, S., Wang, J., Yang, L. and Zhang, J. (2008). Natural recovery of different areas of a deserted quarry in South China. *Journal of Environmental Sciences.* Volume 20, Issue 4, 2008, Pages 476-481

Dunlop, R.E and Catton W.R (1978). Environmental Sociology: A Framework for Analysis. Paper presented at the Annual Meeting of the Rural Sociological, San Francisca, Sept. 1978

EAPC. (2009). East African Portland Cement. http://www.Eastafricanportland.com. cited Dec. 2009.

El-Lakany, M. H. and Yuness, M. I. (1996). Provenance trials of *Casuarina equisetifolia* in Egypt. Early results of height growth. In *Recent Casuarina Research and Development.* Eds. K., Pinyopusarerk, J.W. Turnbull and S.J. Midgley. CSIRO, Canberra:119-123.

EMCA. (1999). Environmental Management and Coordination Act (2000): the Laws of Kenya. Government Printers.

Ferreroa, A., Alejandra, M., Cristina, B. and Zanettia, N. (2007), "Acute and subacute toxicity evaluation of ethanolic extract from fruits of *Schinus molle* in rats", *Journal of Ethnopharmacology* 113 (3): 441–447, 2007-09-25.

Gajaseni, J. and Gajaseni, N. (1999). Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. *Agroforestry Systems,* 46: 3-23.

Gardner, W. (1986). Water content. In: Klute, A. (Ed) Agronomy Monograph 9. *Methods of Soil analysis Part 1: Physical and Mineralogical Methods.* American Society of Agronomy, Madison, Wisconsin, USA, pp. 493-544.

Geology (2005-2010). http://www.geology.com2005-2010.

Ghose, A.K (1999). Issues for Global Mineral Industry: An Agenda of Problems and Opportunities in the New Millenium. In Mining Challenges. "*Proceedings of the International Conferance on Mining Challenges of the 21st Century,* New Delhi, 25 – 27 November, 1999.

Gilmore, A.R. and Matis, D.S. (1981). Effects of past agricultural practices on the soil – phosphorus system and growth of planted pines. *Soil Sci*. 131: 3131 – 319.

Glick, B.R. (2003). Phytoremediation: synergistic use of plants and bacteria to clean up the environment. Biotechnol Adv 21:383–393.

Gough, L.P., Hornick, S.B., and Parr, J.F.M, (1992). Geosciences, agroecosystems and the reclamation of degraded lands, in Wali, M. K., ed., Ecosystem Rehabilitation: The Hague, The Netherlands, SPB Academic Publishing. pp. 47-61.

Hager, H and Seighardt, M. (1984). Damage of forest sites through soil compaction: Soil physical changes on soils of different textures. Central Gesamate. Forstwes. 101: 109 – 110.

Haggar, J.P., Tanner, E.V.J., Beer, J.W. and Kass, D. (1993). Nitrogen dynamics of tropical agroforestry and annual cropping systems. *Soil Biology and Biochemistry,* 45: 1363 – 1378.

Haggar, J.P, Warren, G.P, Beer, J.W., and Kass, D. (1991). Phosphorus availability under alley cropping and mulched and unmulched sole cropped systems in Costa Rica. *Plant and Soil*, 137: 275 – 283.

Hagstrom, J., James W.M. and Skene K.R. (2001). A comparison of structure, development and 232: 81-90.

Hall, R.D. (1980). Land Reclamation With Trees In Iowa. Journal paper no. 5-9987 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Projects No. 2294 and 2210. Presented a t the Symposium on Trees for Reclamation in the Eastern U.S., Lexington, Kentucky, Oct. 27-29, 1980.

Haller, R.D and Baer S. (1995). From Wasteland to Paradise. Germany, Hans H. Koschany: 1-118 Baer S. and Groom. C. Industry and Nature, Haller Park. Mombasa-Kenya. Mombasa,Bamburi Cement Ltd: 1-34.

Haller, R.D. (1974). Rehabilitation of a Limestone Quarry; Report of an experiment. Mombasa – Kenya, July 1974.

Hands, M.R., Harrison, A.F., and Bayliss-Smith, T. (1995). Phosphorus dynamics in slash-and-burn and alley cropping system of the humid tropics. In: Tiessen, H. (Ed.), *Phosphorus in tbhe Global Environment: Transfers, Cycles and Management*. John Wiley, New York, USA, pp155 – 170.

Harwood, C.E, ed. (1992). *Grevillea robusta* in Agroforestry and Forestry: Proceedings of an International Workshop. Nairobi: ICRAF.

Hauser, S. and Kang, B.T. (1993). Nutrients dynamics, maize yield and soil organic matter dynamics in alley cropping with Leucaena leucocephala. In: Mulongoy, K., Merckx, R. (Eds.), Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture. John Wiley and Sons and Sayce publishing, Chichester, UK.

Havlin, J.L. (1999). Soil Fertility and Fertilizers. *Soil Fertility and Fertilizers.* 6th Edition. Prentice Hall.

Hilson G, (2002). An overview of land use conflicts in mining communities. Land use Policy 2002; 19(1), pp.16 – 17.

Horward, S.B. (1997). *Resource Capture and Productivity of Agroforestry Systems in Kenya*. PhD thesis, University of Nottingham, UK, pp. 325.

ICRAF, (1992), A selection of useful trees and shrubs for Kenya: Notes on pastoral communities. ICRAF.

Iponga, D.M., Milton, S.J., and Richardson, D.M. (2008), "Superiority in competition for light: A crucial attribute defining the impact of the invasive alien tree *Schinus molle (Anacardiaceae)* in South African savanna", *Journal of Arid Environments* 72 (5): 612–623, May 2008.

IUCN/ODA (1995) *Kenya's Indigenous Forests: Status, Management and Conservation* (Ed. P. WASS) International Union for the Conservation of Nature, Nairobi, Kenya.

Jackson, N.A., Wallace, J.S., and Ong, C.K. (2000). Tree pruning as a means of controlling water use in an agroforestry System in Kenya. *Forest Ecology and Management*, 126: 133-148.

Johson, D. and Johnson S. (1993). Gardening with Indigenous Trees and Shrubs. Southern Book Publishers (Pty) Ltd.

Johnson, M.S, and Bradshaw, A.D. (1977). Prevention of heavy metal pollution from mine wastes by vegetative stabilisation. *Trans Inst Min Metall* A 86:47–55.

Johnson, D.B., Williamson, J.C. and Bailey, A.J. (1991). Microbiology of soils at opencast coal sites. I. Short and long-term transformation in stockpiled soils. Journal of Soil Science 42, 1-8.

Juo, A.S.R., Franzluebbers, K., Dabiri, A. and Ikhile, B. (1995). Changes in soil properties during long-term fallow and continuous cultivation after forest clearing in Nigeria. *Agriculture, Ecosystems and Environment* 56, 9-18.

Kalinganire, A. (1996). Performance of *Grevillea robusta* in plantations and on farms under varying environmental conditions in Rwanda. *Forest Ecology and Management*, 80: 279–285.

Kang, B.T. (1997), Alley cropping-soil productivity and nutrient recycling. *Forest Ecology and Management*, 95: 75-82.

Kariuki, D.K. (2000). A report of the civil society review of the implementation of agenda 21 in Kenya.

Kashkovsky, G.N. and Kornilova, T.N. (1989). Impact of Mining on the biosphere. Geology and the Environment: an International manual 2. UNESCO publication catalog No. 88150.

Kenya Population Census, (1999). Kenya bureau of Statistics. Government of Kenya. Ministry of Planning.

Kimondo J.M. (1996). Two-year performance of *Casuarina equisetifolia* provenances in Gede, Kenya. In *Recent Casuarina Research and Development.* Eds.

Klute, A. (1986). *Methods of Soil analysis Part 1: Physical and Mineralogical Methods.* Agronomic Series No. 9 American Society of Agronomy Inc. and Soil Science Society of America Inc., Wisconsin, USA, pp. 1118.

Kramer, P.J. (1980). Drought stress and the origin of adaptations. In:*Adaptations to Water and High Temperature Stress* (Eds N. C. TURNER and P.J. Kramer). John Wiley & Sons. New York.

Krzaklewski, W. and Pietrzykowski M. (2002). Selected physicochemical properties of zinc and lead ore tailings and their biological stabilisation. *Water Air Soil Pollut* 141:125–142.

Kuehl, R. O. (1994). Statistical principles of research design and analysis. Duxbury Press, Belmont, California.

Kulshreshtha, K., Rai, A., Mohantry, C.S., Roy, R.K. and Sharma, S.C. (2009). Particulate pollution mitigating ability of some plant species. *Int. J. Environ. Res.*, 3: 137-142

Kumar, G.K., Hegde, R. and Babu, L.C. (2000). Decomposition and nutrient release patterns of leaf litters of mangium (*Acacia mangium*). *Indian Journal of Agroforestry*, 3: 11 – 22.

Kumar, S.K. Sharma, B.K. Sharma, L.P. Gough. (1998). Richness, diversity and evenness of vegetation upon rehabilitation of gypsum mine spoiled lands in the Indian arid zone. *Annals of the Arid Zone* 37:139–145.Lal, R. 1987. *Tropical ecology and physical edaphology*. John Wiley and Sons, Chichester, United Kingdom.

Lal, R. and Stewart, B.A. (1992). Need for land restoration: In R. Lal and B. A. Stewart, editors, Pages 1–11. *Soil restoration*. Advances in Soil Science 17. Springer-Verlag, New York.

Landon, J.R. Ed. (1991). Booker Tropical Soil Manual: a handbook for Soil Survey and Agricultural Land Evaluation in Tropics and Subtropics. Longman Scientific and Technical. Harlow, U.K, pp. 538.

Lapeyrie, F. and Bruchet, G. (1986). Calcium accumulation by two strains, calcicole and calcifuges of mycorrhizal fungus *Paxillus involutus. New Phyto*. 103: 133 – 144.

Laurence, D.C. (2001). Mine closure and the community. *Mining Environmental Management*, 9(4): 10-12.

Lavagne, A. and Moutte, P. (1966). Memorandum redistribution and ecology of the mountain pine (*Pinus uncinata*) in Bay valley (Basses – Aloes). *Rev. For. Fr*. 8: 659 – 674.

Law, L.D. (1983). Mined Land Rehabilitation. UNEP.

Lediges, P.Y. (1974). Variation in drought tolerance in *Eucalyptus viminalis. Labill. Can J. Bot. 22. 489-500.*

Le Houerou H.N. (2000). Utilization of fodder trees and shrubs in the arid and semi-arid zones of west Asia and north Africa. *Arid soil Res*. and Rehabilitation.

Liang, R. and Li, C. (2003). Differences in cluster-root formation and carboxylate exudation in *Lupinus albus* L. under different nutrient deficiencies. *Plant Soil,* 248: 221-227.

Lindsay, W.L. and Schwab, A.P. (1982). The chemistry of iron in soils and its availability to plants. *J Plant Nutr*., 5: 821-840.

Little, R.L. (1977). Some Social Consequences of boom towns. *North Dakota Law Review.* 53(3): 401-425.

Little, R. and Lovejoy S. (1979). Energy Development and Local Employment. *The social science journal.* 16: 2: 29-49.

Livesley, S.J. (1999). *The Distribution and Dynamics of Roots and Soil Nitrogen and Water in Tree Row Agroforestry Systems.* PhD thesis, University of Reading, UK.

Loeppart, R. H., Husker, L.R., Amin, P.K. (1984). Formation of ferric oxyhydroxides from ferrous and ferric perchlorate in stirred calcareous systems. *Soil Sc. Soc. Am. J* 48: 677 – 683.

Lott, J.E. (1998). *Resource Capture and Use in Semi-Arid Over-storey Agroforestry Systems*. PhD thesis, University of Nottingham, UK, pp. 259.

Machadoa, D.G., Kastera, M.P., Binfaréa, R.W., Diasc, M., Santosb, A.R.S., Pizzolattic, M.G., Brighentec, I.M.C., and Rodrigues, A.S. (2007), "Antidepressant-like effect of the extract from leaves of *Schinus molle* L. in mice: Evidence for the involvement of the monoaminergic system", *Progress in Neuro-Psychopharmacology and Biological Psychiatry* (Elsevier) 31 (2): 421–428, 2007-03-30.

Marion, G.M, Van Cleve, K., Dyrness, C.T., Black, C. (1993). The soil chemical environment along a forest primary successional sequence along the Tanana River flood plain, interior Alaska. Can. J. For. Res. 23: 914 – 922.

Marrs, R. H., Roberts, R. D., Skeffington, R. A. and Brad shaw, A. D. (1981). Ecosystem development on naturally colonized china clay wastes. II. Nutrient compartmention. *J. Ecol*. 69: 163-169.

Marschner, H. (1995). Mineral Nutrition of Higher Plants. Academic Press, NewYork.

Masiku, A.N. (2008). Economic, environmental and social impact of small-scale mining.
http://www.32.org. cited on 7th April, 2008.

Mathu, E.M and Davies. T. C. (1996). Geology and the Environment in Kenya; *Journal of African earth Sciences*, vol. 23. No.4.

Maybaum, M.A. (2003). Ngomongo Environmental and Poverty Alleviation Initiative. Global 500 Forum. UNEP.

Maynard D.G, Mallet, K.I., Myrholm, C.L. (1997). Sodium carbonate inhibits emergence and growth of greenhouse – grown spruce. *Can. J. Soil Science*. 77: 99 – 105

Mazera, N. (2009). "From the dump rose a flourishing eco-village." Daily Nation. Thursday March 12, 2009.

McCready, P. (2007). Mining Journal Special publication, Kenya. Mining Communication Ltd. UK.

Mendez, M.O., Glenn, E.P. and Maier, R.M. (2007). Phytostabilization potential of quailbush for mine tailings: growth, metal accumulation, and microbial community changes. *J Environ Qual* 36:245–253.

MII. (2010) Mineral Information Institute - Affiliate of SME foundation. http://www.reclsuccessindus.htm.

Miller, R.M. and R.E. Cameron. (1976). Some effects of soils microbiota on topsoil storage during surface mining. pp 131-139. In Transactions of the 4th Symposium on Surface Mining and Reclamation. National Coal Association, Washington.

Millimo, P.B. (1989). Growth and survival of Australian tree species in field trials in Kenya. In: *Tropical Trees: the Potential for Domenstication and Rebuilding of Forest Resources* (Eds R.B.B. Leaky and A.C. Newton). HMSO. London.

Misra, A. and Tyler, G. (2000). Effects of wet and dry cycleso in calcareous soils on mineral nutrient uptake of two grasses: Agrostis stolonifera L and Festuca ovina L. *Plant and Soil* 224: 297-303. Kluwer Academic publishers. The Netherlands.

Moffat, A.J. (2001). Increasing woodland in urban areas in the UK - meeting ecological and environmental standards. In *Forests in a changing landscape.* Proceedings of the 16th Commonwealth Forestry Conference, Fremantle, Australia, 18-25 April 2001.

Montgomery, D. C. (1996). Design and Analysis of Experiments, 4th ed. Wiley, New York.

Moynahan, O.S., Zabinski, C.A., and Gannon, J.E. (2002). Microbial community structure and carbon-utilization diversity in a mine tailings revegetation study. *Restor Ecol* 10:77–87.

Mugo, R. (2001). "Tiomin mired in controversy from day one". East African Standard, 5 February 2001.

Mulayta, J. (2000). *Root Development and Interactions in Drylands: Focusing on Melia volkensii with Social Economic Evaluations*. PhD thesis, Dundee University, UK, pp. 173.

Mummey, D.L, Stahl, P.D., and Buyer, J.S. (2002). Soil microbiological properties 20 years after surface mine reclamation: spatial analysis of reclaimed and undisturbed sites. *Soil Biol Biochem* 34:1717–1725.

Munshower, F.F. (1994). Practical Handbook of Disturbed land Revegetation. Boca Raton, FL. Lewis Publishing. London.

Muthuri, C. W. (2004). *Impact of Agroforestry on crop Performance and Water Resources in Semi-arid Central Kenya.* PhD Theses, Kenyatta University of Agriculture and Technology, Kenya. pp. 49.

Mwangi, J (2010). Quarry Disaster Buries 5 workers in Kenya. http://www.demotiximages.com/news/237349/five-buried-quarry-kenya.

Nambiar, E.K.S. (1983). Root development and configuration in intensively managed radiate pine plantations. *Plants and Soils*, 71: 37 - 47.

Nichols, O.G. and Gardner, J.H. (1998). Long term monitoring of fauna in bauxite mined areas of the Darling Range. In *Proceedings of the Australian Centre for Minesite Rehabilitation Research workshop on Fauna Habitat Reconstruction*. Adelaide, Australia, 10-11 October 1997.

Nichols, O.G., Koch, J.M., Taylor, S. and Gardner, J.H. (1991). Conserving biodiversity. In *Proceedings of the Australian Mining Industry Council Environmental Workshop*, pp. 116-136. Perth, Australia, October 1991.

Nicolau, J.M. and Asensio, E. (2000). Rainfall erosion on opencast coal mine lands: ecological perspective. In: Haigh, M.J. (Ed.), Reclaimed Land: Erosion Control, Soils and Ecology. A.A. Balkema, Rotterdam, The Netherlands, pp. 51–73.

Njoroge, C.R.K. and Macharia, P.N, (2007). The soils of the proposed petrol station development site at the Athi River, off Nairobi – Mombasa road (Machachos District). KARI. Kenya Soil Survey site evaluation report No. P 129. February, 2007.

Noborio, K. (2001). Measurements of soil water content and electrical conductivity by time domain reflectometry: a review. *Computers and Electronics in Agriculture,* 31: 213-237.

Oballa, P.O., Konuche, P.K.A. and Thogo S. (1997) Observation on Growth Performances of some valuable Indigenous Tree Species. KEFRI Publication, Nairobi Kenya.

Okorio, J. (2000). *Light Interception and Water Use in Boundary Planting Agroforestry Systems*. PhD thesis, Reading University, UK, pp 230.

Olsen, S.R and Sommers, L.E (1984). Phosphorus: In methods of soil analysis Part 2. Ed Page *et al*.

Omondi, G. (2010). Cheap Imports pile pressure on E. Africa Cement Producers. Business Daily. Monday, September 20, 2010. Published by the Nation Media Group.

Ong, C.K., Black, C.R., Wallace, J.S., Khan, A.A.H., Lott, J.E., Jackson, N.A., Howard, S.B. and Smith, D.M. (2000). Productivity, microclimate and water use in *Grevillea robusta*-based agroforestry systems on hillslopes in semi-arid Kenya. *Agriculture, Ecosystems and Environment* **80**: 121-141.

Osonubi, O. and Davies, W.J. (1978). Solute accumulation in leaves and roots of woody plants subjected to water stress. *Oecologia* 32: 323-332.

Osterkamp, W.R. and Joseph, W.L. (2000). Climatic and hydrologic factors, Chapter 8, pp 193-215, In:Barnhisel, R.I., Darmody, R.G., and Daniels, W.L. (eds.), Reclamation of drastically disturbed lands, pp 1082.

Osumo, E.S (2001). A Brief Report on the mining Sector. Mines and Geology Communication.

Otieno, D.O., Kinyamario J.I. and Omenda T.O. (2001). Growth features of *Acacia tortilis and Acacia xanthophloea* seedlings and their response to cyclic soil drought stress. East African Wild Life Society. *Afr. J. Ecol*. 39: 126-132.

Palzer, C. (2002). Tree Nursery Manual for Eritrea. *Technical Handbook No. 26.* Regional Land Management Unit, RELMA/Sida. ICRAF House, Gigiri, Nairobi, Kenya.

Passioura, J.B. (1982). Water soil-plant-atmosphere continuum. In Pirson A and Zimermann, M.H. (eds.), *Encyclopedia of Plant Physiology Vol. 12B.* Springer-Verlag, Berlin, Germany, pp. 478-533.

Pope, A.C. (2004). Cardiovascular mortality and long-term exposure to particulate matter air pollution. *Circulation*, 109:71– 77.

Prach, K. and Pysek, P. (2001). Using spontaneous establishment of woody plants in Central European derelicts sites and their potential for reclamation. *Restor. Ecol*., 2: 190-197.

Pugnaire, I. F., Serrano, L. and Pardos, J. (1999). Constraints by plant water stress on plant growth. In: Pessarakli, M. (ed.), *Handbook of Plant and Crop Stress*, Second Edition, Marcel Dekker, New York, USA, pp. 271-283.

Radersma, S., and Ong, C.K (2004). Spatial distribution of root length density and soil water of linear agroforestry systems in sub-humid Kenya: Implication for agroforestry models. *Forest Ecology and Management*, 188: 77-89.

Rao, A.V and Richa, T.A.K. (2002). Growth of different tree species and their nutrient uptake in limestone mine spoil as influenced by arbuscular mycorrhizal (AM)- fungi in Indian arid zone. *Journal of Arid Environments* ISSN 014-1963 Coden Jaendr vol. 51, pp 113-119.

Raven, J.A. and Andrews, M. (2010). Evolution of tree nutrition. *Tree Physiology* 30, 1050-1071.

Rhoads, J. D. (1982). In Methods of Soil Analysis, Part 2. Second Edition (A. L. Page, R.H. Miller and D.R. Keeney, eds.). *American Society of Agronomy*, Inc., Madison.

Ridley, A.M., Simpson, R.J., and White, R.E. (1999). Nitrate leaching under phalaris, cocksfoot and annual ryegrass pastures and implications for soil acidification. *Australian Journal of Agricultural Research*, 50: 55 – 63.

Roberts, R.D. and Roberts. J.M. (1986). The selection and management of soils in landscape schemes. Pages 99–126 in A. D. Bradshaw, D. A. Goode, and E. H. P. Thorp, editors. *Ecology and design in landscape*. Blackwell, Oxford, England.

Roberts, R.D., Marrs, R.H., Skeffington, R.A. and Brad Shaw, A.D. (1981). Ecosystem development on naturally colonized China clay wastes. I. Vegetation changes and overall accumulation of organic matter and nutrients. *J. Ecol*. 69: 153-161.

Ruthof, K.X. (1997). Improving the success of limestone quarry revegetation. *Cave and Karst Science* 24:117–125. No. 3 December 1997. Transaction of the British Association.

Sabine, B. (1996). Rehabilitation of Disused Limestone Quarries through Reafforestation (Baobab farm, Mombasa, Kenya) – Rehabilitation of Cement Factory Quarries. World Bank/UNEP Africa Forestry Policy Forum. Nairobi 29-30th August 1996.

Saggerson, E.P. (1991). Geology of the Nairobi area (Report No. 98), Ministry of Environment and Natural Resources, Mines and Geology Department, Government of Kenya.

Sanchez, P.A. (1995). Science in Agroforestry. *Agroforestry Systems*, 30: 5-55.

Sarrailh, J.M. (2001). Native or exotic plants for mining sites. Experiments in New Caledonia. In *Forage production and rehabilitation of mine sites*, Commission Pacifique Sud.

Sasson, M. (1996). Mining Environmental Management. "Quarry wasteland to nature trail" The Mining Journal Ltd.

Schoenborn, A. (2003). Baobab Farm – a green paradise, where wasteland had been. EcoEng Newsletter No. 8, Dec. 2003 – Interview Haller.

Schroth, G. (1999). A review of below-ground interactions in agroforestry, focusing on mechanisms and management options. *Agroforestry Systems,* 43:5-34.

Schroth, G. and Lehmann J (2003). Contrasting effects of roots and mulch from three agroforestry tree species on yields of alley cropped maize. *Agriculture, Ecosystems and Environment* 54, 89 – 101.

Schroth, G., Lehmann, J., Rodriques, M.R.L., Barros, E. and Macedo, J.R.V. (2001). Plant-soil interactions in multi-strata agroforestry in humid tropics. *Agroforestry Systems.* 53, 85 -10.

Sharma, S.C. and Roy, R.K. (1997). Indian J. Environmental Protection. 17 Volume (10). 724.

Shaxson, F. and Barber, R. (2004). Optimizing Soil Moisture for Plant Production. The significance of soil porosity. FAO Soils Bulleting 79. Food and Agriculture Organization of United Nation. Rome. ISBN 92-5-104944-0.

Siachoono, S.M. (2010). *International Journal of Biodiversity and Conservation* Vol. 2(2) pp. 019-025 February, 2010. *Review* Land reclamation efforts in Haller Park, Mombasa.

Sinha, R.K., Pandey, D.K. and Sinha, A.K. (2000). Mining and the Environment: a case study from Bijolia quarrying site in Rajasthan, India. *The Environmentalist*, 20, 195-203.

Sinha, S. and Banerjee, S. P. (1994). A Method for Estimating Fugitive Particulate Emission from Haul Roads in Opencast Coal Mines and Mitigative Measures', in S. P. Banerjee (ed.), *Proceedings of Second National Seminar on Minerals and Ecology*, Dhanbad, India, pp. 217–227.

Skene, K.R. (1998). Cluster roots: some ecological considerations. *J. Ecol.,* 86: 1060–1064.

Skene, K.R. (2000). Pattern formation in cluster roots : Some developmental and evolutionary considerations. *Ann. Bot.* 85: 901-908.

Slinn, W.G.N. (1999). *Atmospheric Environment* 16, pp1785.

Smit, N. (1999). Guide to the Acacias of South Africa. Briza: Pretoria.

Smith, C.J., Peoples, M.B., Keerthisinghe, G. A and James, T. R. (1994). "Effect of surface applications of lime, gypsum and phosphogypsum on the alleviating of surface and subsurface acidity in a soil under pasture". *Australian Journal of Soil Research* 32 (5): 995–1008.

Smith, K. and Petley, D.N. (2009). Environmental Harzards – Assessing risk and reducing disaster. 5^{th} edition, Routledge. ISBN 978-0-415-42865-1.

Smith, R.M. and Sobek, A.A. (1978). Physical and chemical properties of overburdens, spoils, wastes, and new soils. Pages 149–172 in F. W. Schaller and P. Sutton, editors. *Reclamation of drastically disturbed lands*. American Society of Agronomy, Madison, Wisconsin.

Smyth T.J. and Cassel, D.K. (1995). Synthesis of long-term soil management research on Ultisols and Oxisols in the Amazon. In: Lal, R. and Stewart, B.A. (eds) *Soil Management – Experimental Bases for Sustainability and Environmental Quality*. Lewis Publishers, Boca Raton, Florida, pp, 13 – 59.

Southam, G. and Bevberidge. (1992). Enumeration of thiobailli within pH-neutral and acidic mine tailings and their role in the development of secondary mineral soil. Appl. Environ. Microbiol. 58: 1904-1912.

Sprent, J.I. (1995). Legume trees and shrubs in the tropics: N_2 fixation in perspective. *Soil Biology and Biochemistry*. Vol. 27: 401 – 407.

Sprent, J.I. and Sprent, P. (1990). Nitrogen Fixing Organisms. Chapman and Hall, New York.

Staff, H., and Berg, B. (1982). Accumulation and release of plant nutrients in decomposing Scots pine needle litter. *Canadian Journal of Botany*, 60: 1561 - 1568.

Stark, J.M. and Redente, E.F. (1987). Production potential of stockpiled topsoil. Soil Science 144(1), 72-76.

Talibudeen, O. (1981). Precipitation, In: D.J. Greenland and M.H.B. Hayes, eds. The chemistry of soil processes. John Wiley and sons. New York. pp 81 – 114.

Tiedemann, A.R, and Klemmedson, J.O. (2004). Responses of desert grassland vegetation to mesquite removal and regrowth. *J Range Manage* 57:455–465.

Tiessen, H, Cuevas, E. and Chacon P. (2002). The role of soil organic matter in sustaining soil fertility. *Nature* 371, pp783 – 785.

Thompson, A., Howarth, C.L., Goodwin, A., Buckley, C, and Harris, K. (2007). Good Practice Guidance on Controlling the Effects of Surface Mineral Working on the Water Environment. Capita Symonds. Sustainable Land-Won and Marine Dredged Aggregate Minerals Programme. Project Title. SAMP 3B.8.

Tordof, G.M., Baker, A.J.M. and Willis, A.J. (2000). Current approaches to the revegetation and reclamation of metalliferous mine wastes. *Chemosphere* 41 (2000) 219-228.

Toy, T.J. and Griffith, J.J. (2001). Changing surface-mine reclamation practices in Minas Gerais, Brazil. *International Journal of Surface Mining, Reclamation and Environment*, 15(1): 33-51.

Vardaka, E., Cook, C.M. Lanaras, T. Sgardelis, S.P. and Pantis, J.D. (1995). Effect of dust from a limestone quarry on the photosynthesis of Quercus coccifera, and evergreen sclerophyllous shrub. Bull. Environ. Contam. Toxicol. pp 54:414–419.

Vartanyan, G.S. (1989). International Workshop on the Impact of Mining on the evironment; Tallinn and Leningrad, USSR: proceedings; Unesco-sponsored programmes and publications. Publ:1989; vol. 2.

Whitlow, R. (1991). Environmental Impact Assessment and the mining industry: In Third UNESCO Regional Training Programme in Mining Geology, Zimbabwe. UNESCO. 1991.

Wiegleb, G., and Felinks B. (2001). Predictability of early stages of primary succession in post-mining landscapes of lower Lusatia. Appl. Veg. Sci., 4: 5-18.

Wong, M.H. (2003). Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. *Chemosphere* 50:775–780.

Xia, H.P. and Cai, X.A. (2002). Ecological restoration technologies for mined lands: a review. China *J Appl Ecol* 2002, 13(11):1471– 7a.

Zhang, P. (1996). *Water Use in a Poplar Tree Pasture System*. PhD thesis, University of Reading, UK. pp. 78.

APPENDIXES

Appendix I Daily Rainfall from January 2006 to December 2008

Daily Rainfall data 2006

Date	Jan-06	Feb-06	Mar-06	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06
1	-	-	15	-	-		-	-	-	-	9.3	3
2	-	-	9	-	6	-	-	-	-	-	11	5
3	7	-	10.5	3.5	18.5	-	-	-	-	-	2.4	-
4	2.5	-	24	9.5	21	-	-	-	-	-	-	-
5	-	-	-	12	1.2	-	-	5	-	-	2	-
6	-	-	-	11.2	-	-	-	-	-	-	7.3	-
7	-	-	1.5	19.2	-	-	-	-	-	-	2.2	-
8	-	0	-	17.1	25	-	-	-	-	-	5.2	-
9	-	-	-	14	5.5	-	-	-	-	-	-	-
10	-	-	-	2.1	-	-	-	-	-	-	-	-
11	-	-	-	8.3	-	-		-	-	-	23.5	-
12	-	-	-	-	-	-	-	-	-	-	14	-
13	2	-	-	3	-	-	-	-	-	-	7	-
14	-	-	-	2.8	25.5	-	-	-	-	-	7	6.5
15	-	-	-	-	1	-	-	-	-	-	3	-
16	-	-	-	2.3	-	-	-	-	-	-	13.5	-
17	-	-	-	-	-	-	-	-	-	-	2.2	-
18	-	-	-	-	-		-	-	-	-	5	-
19	-	-	-	7.5	-	-	-	-	-	-	5	-
20	-	-	-	-	-	-	-	-	-	-	3	-
21	10	-	-	-	-	-	-	-	30	-	-	-
22	-	-	-	-	-	-	-	-	-	-	1	-
23	-	-	-	-	-	-	-	-	-	-	27.5	-
24	-	-	-	6	-	-	-	-	-	-	0.5	26
25	-	-	-	-	-	-	-	-	-	-	-	7
26	-	-	-	-	-	-	-	-	-	-	11	7.5
27	-	1.5	-	1	-	-	-	3	-	-	2.5	85
28	-	21	-	-	-	-	-	-	2	2	-	18
29	-	-	-	9.5	-	-	-	-	-	-	-	8
30	-	-	-	-	-	-	-	-	-	-	2.5	7
31	-	-	-		-	-	-	-	-	-	-	25
total	21.5	22.5	60	129	103.7	0	0	8	34	2	167.6	198
Ave	0.694	0.726	1.935	4.161	3.345	0	0	0.258	1.097	0.065	5.406	6.387

Daily Rainfall data 2007

Date	Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
1	2	-	-	-	36.5	-	-	-	-	-	-	-
2	5	-	-	-	-	-	-	-	-	-	-	-
3	7	-	-	-	-	-	-	-	-	-	-	-
4	14.5	-	-	-	-	-	-	-	-	-	-	-
5	22.5	-	-	-	-	-	-	-	-	2	1.5	-
6	-	-	-	-	-	-	-	-	-	2	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	1	-	-	-	7.5	-	9	-
9	-	-	-	-	-	-	-	-	-	1	2.5	-
10	-	-	-	4	-	-	-	-	-	-	-	-
11	-	-	-	33.5	-	-	-	-	-	-	-	-
12	-	-	10	4	0.5	-	-	-	4.6	-	4	-
13	-	-		4.5	-	-	-	-	2.5	-	-	-
14	-	-	-	-	-	-	-	-	-	-	20	-
15	-	-	-	-	-	-	-	-	-	-	13.5	-
16	-	-	-	10.5	-	-	-	-	-	-	-	-
17	-	-	-	26	-	-	-	-	-	-	-	-
18	-	-	-	26	60.5	-	-	-	-	-	-	
19	-	-	-	13.5	3.5	-	-	9.5	-	-	8	52.5
20	-	-	-	0.5	-	-	-	1.5	-	-	15.5	-
21	-	-	-	0.5	-	-	-	-	-	-	-	-
22	-	-	-	3.5	-	-	-	-	-	-	-	-
23	-	-	-	24	-	-	-	-	-	-	-	-
24	-	-	-	40.5	-	-	-	-	-	-	-	-
25	-	-	-	12.5	-	-	-	-	-	-	-	-
26		-	-	4	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	20.3	-	-	-	-	-
28	-	-	-	43	-	-	1	-	-	-	-	-
29	-	-	-	25	-	-	-	-	-	-	-	-
30	-	-	-	23	-	-	-	-	-	-	-	-
31	9.5	-	-	-	-	-	-	-	-	-	-	-
total	60.5	0	15	298.5	102	0	21.3	11	18.6	5	74	52.5
Ave	1.952	0	0.484	9.629	3.29	0	0.687	0.355	0.6	0.161	2.387	1.694

Daily Rainfall data 2008

Date	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08
1	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-		-	-
3	-	-	-	-	-	-	-	-		5	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	5.5	-	-	-	-	-
6	-		4	-	-	-	19.5	-	-	1.5	-	-
7	-		4	-	-	-	-	-	-	-	3.5	-
8	-	11.5	1.5	-	5	-	-	-	3	-	16.5	-
9	-	-	-	-	3	-	-	-	17.3	-	11	-
10	-	-	-	5.4	-	-	-	-	1.5	-	8.2	-
11	-	-	-	2.5	-	-	-	-	8.5	-	1.2	-
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-
14	40	7.5	-	-	-	-	-	-	-	-	-	-
15	5.5	4	11.5	-	-	-	-	-	-	-	-	-
16	9.5	-	-	-	-	-	-	-	-	6.5	-	-
17	3.5	-	-	-	-	-	-	-	-	-	3	-
18	4.5	-	2.7	6	-	-	-	-	-	-	-	-
19	6.5	-	8	16	-	-	-		-	-	-	-
20	-	-	-	7	-	-	-	-	-	16.5	-	-
21	-	-	-	6	-	-	-	-	-	8		-
22	-	-	33.3	3	-	-	-	-	-	5	-	-
23	-	-	8	14	-	-	-	-	-	14	-	-
24	-	-	33	-	-	-	-	-	-	6.5	-	-
25	-	-	0.5	-	-	-	-	-	-	-	-	-
26	-	-	24	-	-	-	-	-	-	-	-	-
27	-	-	21	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-
total	69.5	23	151.5	59.9	8	0	0	0	30.3	63	0	0
Ave	2.242	0.742	4.887	1.932	0.258	0	0	0	0.977	2.032	0	0

Appendix II: Plant Growth (cm) from March 2006 to March 2009

Month	Block	Species	Height	D-base	D-1meter
March06	A	Schinus	132.25	2.38	0.49
March06	A	Acacia	68.00	1.17	0.00
March06	A	Casuarina	123.00	0.86	0.17
March06	A	Grevillea	103.25	1.66	0.16
March06	B	Schinus	170.75	2.84	1.14
March06	B	Acacia	80.50	1.59	0.00
March06	B	Casuarina	121.50	1.86	0.81
March06	B	Grevillea	97.25	1.78	0.06
March06	C	Schinus	180.00	3.23	1.26
March06	C	Acacia	72.25	1.35	0.00
March06	C	Casuarina	164.50	1.69	0.73
March06	C	Grevillea	112.50	2.03	0.38
April-06	A	Schinus	144.38	2.76	0.67
April-06	A	Acacia	73.80	1.22	0.00
April-06	A	Casuarina	130.75	1.26	0.29
April-06	A	Grevillea	76.08	1.70	0.00
April-06	B	Schinus	178.25	3.26	1.34
April-06	B	Acacia	86.25	1.97	0.00
April-06	B	Casuarina	146.75	2.15	0.94
April-06	B	Grevillea	104.25	2.05	0.16
April-06	C	Schinus	199.63	3.65	1.64
April-06	C	Acacia	73.00	1.51	0.00
April-06	C	Casuarina	177.00	1.66	0.89
April-06	C	Grevillea	119.75	2.19	0.48
May06	A	Schinus	173.83	3.60	1.21
May06	A	Acacia	77.33	1.30	0.00
May06	A	Casuarina	148.58	1.58	0.41
May06	A	Grevillea	142.92	2.19	0.69
May06	B	Schinus	210.92	4.32	2.14
May06	B	Acacia	98.00	2.19	0.16
May06	B	Casuarina	172.83	2.72	1.16
May06	B	Grevillea	125.67	2.44	0.43
May06	C	Schinus	229.58	4.51	2.36
May06	C	Acacia	76.08	1.70	0.00
May06	C	Casuarina	204.83	2.05	1.15
May06	C	Grevillea	134.17	2.58	0.68
june06	A	Schinus	181.63	3.92	1.40
june06	A	Acacia	80.00	1.37	0.00
june06	A	Casuarina	158.25	1.76	0.50
june06	A	Grevillea	161.88	2.44	0.92
june06	B	Schinus	228.25	4.72	2.68
june06	B	Acacia	109.50	2.33	0.62
june06	B	Casuarina	212.00	3.17	1.53
june06	B	Grevillea	144.75	2.86	0.88

Plant Growth (cm). Cont'd

Month	Block	Species	Height	D-base	D-1meter
june06	C	Schinus	260.50	5.20	3.00
june06	C	Acacia	78.75	1.78	0.00
june06	C	Casuarina	222.63	2.59	1.37
june06	C	Grevillea	145.13	2.90	0.86
July06	A	Schinus	183.25	3.95	1.41
July06	A	Acacia	81.63	1.43	0.00
July06	A	Casuarina	163.63	1.82	0.56
July06	A	Grevillea	164.13	2.55	1.02
July06	B	Schinus	237.13	5.03	2.88
July06	B	Acacia	126.75	2.50	0.73
July06	B	Casuarina	256.63	3.70	1.83
July06	B	Grevillea	148.88	3.11	1.06
July06	C	Schinus	272.00	5.55	3.38
July06	C	Acacia	84.25	1.88	0.00
July06	C	Casuarina	239.63	2.92	1.66
July06	C	Grevillea	148.00	3.06	0.96
August06	A	Schinus	184.25	4.02	1.43
August06	A	Acacia	82.13	1.48	0.00
August06	A	Casuarina	170.88	1.93	0.62
August06	A	Grevillea	166.88	2.65	1.09
August06	B	Schinus	246.25	5.18	3.04
August06	B	Acacia	142.25	2.66	0.94
August06	B	Casuarina	278.75	4.06	2.15
August06	B	Grevillea	151.13	3.30	1.15
August06	C	Schinus	283.13	5.75	3.63
August06	C	Acacia	91.13	1.92	0.00
August06	C	Casuarina	252.75	3.04	1.76
August06	C	Grevillea	154.13	3.26	1.04
September06	A	Schinus	185.00	4.06	1.45
September06	A	Acacia	85.13	1.56	0.00
September06	A	Casuarina	179.88	2.07	0.66
September06	A	Grevillea	168.00	2.71	1.13
September06	B	Schinus	251.88	5.38	3.20
September06	B	Acacia	159.75	2.84	1.20
September06	B	Casuarina	305.63	4.42	2.51
September06	B	Grevillea	156.50	3.47	1.24
September06	C	Schinus	289.75	6.04	3.83
September06	C	Acacia	103.50	2.00	0.32
September06	C	Casuarina	266.38	3.21	1.84
September06	C	Grevillea	164.50	3.45	1.18
October06	A	Schinus	186.25	4.09	1.47
October06	A	Acacia	86.75	1.62	0.00
October06	A	Casuarina	189.13	2.27	0.76
October06	A	Grevillea	168.63	2.77	1.18

Plant Growth (cm). Cont'd

Month	Block	Species	Height	D-base	D-1meter
October06	B	Schinus	261.50	5.52	3.32
October06	B	Acacia	183.75	3.04	1.43
October06	B	Casuarina	321.38	4.63	2.76
October06	B	Grevillea	164.00	3.61	1.31
October06	C	Schinus	293.75	6.22	3.95
October06	C	Acacia	115.75	2.09	0.56
October06	C	Casuarina	276.00	3.38	1.96
October06	C	Grevillea	174.13	3.60	1.25
November06	A	Schinus	188.67	4.16	1.48
November06	A	Acacia	89.67	1.67	0.13
November06	A	Casuarina	217.83	2.54	1.00
November06	A	Grevillea	172.58	2.88	1.26
November06	B	Schinus	278.42	5.67	3.46
November06	B	Acacia	203.92	3.21	1.76
November06	B	Casuarina	346.00	4.93	2.99
November06	B	Grevillea	174.75	3.81	1.42
November06	C	Schinus	303.00	6.40	4.20
November06	C	Acacia	138.75	2.33	0.76
November06	C	Casuarina	286.92	3.62	2.21
November06	C	Grevillea	191.92	3.68	1.34
December06	A	Schinus	191.50	4.24	1.54
December06	A	Acacia	94.38	1.86	0.21
December06	A	Casuarina	253.00	3.01	1.34
December06	A	Grevillea	188.50	3.06	1.43
December06	B	Schinus	299.50	5.91	3.73
December06	B	Acacia	231.38	3.72	2.30
December06	B	Casuarina	367.75	5.48	3.46
December06	B	Grevillea	186.38	4.00	1.53
December06	C	Schinus	320.00	6.72	4.53
December06	C	Acacia	162.75	2.70	1.16
December06	C	Casuarina	309.13	4.13	2.61
December06	C	Grevillea	209.63	3.91	1.48
January07	A	Schinus	193.75	4.30	1.65
January07	A	Acacia	107.50	2.09	0.40
January07	A	Casuarina	288.50	3.25	1.68
January07	A	Grevillea	200.63	3.24	1.56
January07	B	Schinus	309.25	6.22	3.94
January07	B	Acacia	248.38	4.24	2.67
January07	B	Casuarina	382.75	6.03	3.78
January07	B	Grevillea	196.75	4.18	1.62
January07	C	Schinus	330.88	6.92	4.83
January07	C	Acacia	171.50	3.19	1.49
January07	C	Casuarina	328.50	4.39	2.85

Plant Growth (cm). Cont'd

Month	Block	Species	Height	D-base	D-1meter
January07	C	Grevillea	222.38	4.15	1.68
February07	A	Schinus	195.06	4.42	1.67
February07	A	Acacia	111.38	2.12	0.43
February07	A	Casuarina	308.25	3.45	1.78
February07	A	Grevillea	208.00	3.36	1.67
February07	B	Schinus	313.25	6.50	4.05
February07	B	Acacia	265.88	4.44	2.81
February07	B	Casuarina	396.50	6.33	3.97
February07	B	Grevillea	203.25	4.31	1.69
February07	C	Schinus	337.25	7.02	5.00
February07	C	Acacia	177.75	3.39	1.59
February07	C	Casuarina	341.75	4.57	3.03
February07	C	Grevillea	231.25	4.28	1.80
March07	A	Schinus	196.00	4.46	1.67
March07	A	Acacia	113.13	2.13	0.44
March07	A	Casuarina	318.88	3.58	1.87
March07	A	Grevillea	210.63	3.46	1.71
March07	B	Schinus	315.25	6.63	4.11
March07	B	Acacia	270.00	4.59	2.98
March07	B	Casuarina	402.88	6.49	4.18
March07	B	Grevillea	207.50	4.41	1.76
March07	C	Schinus	344.00	7.15	5.15
March07	C	Acacia	180.88	3.53	1.35
March07	C	Casuarina	354.88	4.69	3.16
March07	C	Grevillea	235.25	4.41	2.01
April07	A	Schinus	197.25	4.35	1.73
April07	A	Acacia	106.63	2.26	0.50
April07	A	Casuarina	330.63	3.87	2.04
April07	A	Grevillea	208.63	3.53	1.70
April07	B	Schinus	319.88	6.32	4.09
April07	B	Acacia	236.88	4.84	3.29
April07	B	Casuarina	439.38	6.87	4.33
April07	B	Grevillea	208.00	4.51	1.77
April07	C	Schinus	349.50	7.16	5.13
April07	C	Acacia	149.63	3.96	2.14
April07	C	Casuarina	397.00	5.51	3.70
April07	C	Grevillea	230.00	4.35	1.94
May07	A	Schinus	198.42	4.37	1.74
May07	A	Acacia	111.42	2.47	0.56
May07	A	Casuarina	351.00	4.16	2.25
May07	A	Grevillea	210.42	3.59	1.73
May07	B	Schinus	325.50	6.25	4.29
May07	B	Acacia	245.58	5.12	3.67
May07	B	Casuarina	486.75	7.23	4.78

Plant Growth (cm). Cont'd

Month	Block	Species	Height	D-base	D-1meter
May07	B	Grevillea	209.50	4.55	1.78
May07	C	Schinus	353.17	7.18	5.15
May07	C	Acacia	155.42	4.16	2.37
May07	C	Casuarina	416.58	5.75	3.93
May07	C	Grevillea	231.75	4.41	2.00
June07	A	Schinus	199.63	4.40	1.75
June07	A	Acacia	114.38	2.59	0.73
June07	A	Casuarina	367.88	4.45	2.34
June07	A	Grevillea	211.88	3.64	1.75
June07	B	Schinus	332.75	6.43	4.42
June07	B	Acacia	253.38	5.32	3.85
June07	B	Casuarina	514.50	7.51	5.03
June07	B	Grevillea	211.13	4.58	25.68
June07	C	Schinus	355.00	7.21	5.20
June07	C	Acacia	161.88	4.39	2.50
June07	C	Casuarina	435.25	6.13	4.12
June07	C	Grevillea	233.63	4.45	2.04
July07	A	Schinus	201.00	4.42	1.77
July07	A	Acacia	117.13	2.66	0.86
July07	A	Casuarina	379.50	4.07	2.49
July07	A	Grevillea	212.88	3.66	1.77
July07	B	Schinus	336.63	6.46	4.45
July07	B	Acacia	257.00	5.52	4.04
July07	B	Casuarina	537.75	7.78	5.19
July07	B	Grevillea	212.50	4.58	49.57
July07	C	Schinus	355.75	7.26	5.24
July07	C	Acacia	166.38	4.60	2.61
July07	C	Casuarina	456.25	6.40	4.15
July07	C	Grevillea	235.63	4.47	2.06
August07	A	Schinus	201.63	4.47	1.77
August07	A	Acacia	118.75	2.74	0.87
August07	A	Casuarina	386.50	4.84	2.57
August07	A	Grevillea	214.00	3.80	1.79
August07	B	Schinus	338.13	6.50	4.50
August07	B	Acacia	259.63	5.69	4.23
August07	B	Casuarina	549.38	8.02	5.33
August07	B	Grevillea	212.38	4.56	1.83
August07	C	Schinus	356.25	7.33	5.28
August07	C	Acacia	171.63	4.72	2.70
August07	C	Casuarina	456.50	6.63	4.46
August07	C	Grevillea	237.00	4.24	2.08
September07	A	Schinus	202.38	4.48	1.78
September07	A	Acacia	119.63	2.76	0.95
September07	A	Casuarina	389.00	4.93	2.62

Plant Growth (cm). Cont'd

Month	Block	Species	Height	D-base	D-1meter
September07	A	Grevillea	214.88	3.71	1.81
September07	B	Schinus	338.88	6.53	4.59
September07	B	Acacia	263.75	5.94	4.42
September07	B	Casuarina	565.50	8.30	5.60
September07	B	Grevillea	213.38	4.61	1.84
September07	C	Schinus	356.50	7.38	5.32
September07	C	Acacia	178.13	4.98	2.85
September07	C	Casuarina	465.75	6.86	4.51
September07	C	Grevillea	237.63	4.40	2.11
October07	A	Schinus	204.33	4.50	1.79
October07	A	Acacia	122.08	2.88	1.15
October07	A	Casuarina	392.58	5.05	2.74
October07	A	Grevillea	215.50	3.74	1.84
October07	B	Schinus	339.92	6.54	4.62
October07	B	Acacia	266.25	6.23	4.71
October07	B	Casuarina	577.58	8.61	5.86
October07	B	Grevillea	214.83	4.63	1.86
October07	C	Schinus	357.17	7.47	5.39
October07	C	Acacia	186.50	5.17	3.05
October07	C	Casuarina	478.75	7.15	4.69
October07	C	Grevillea	239.00	4.57	2.15
November07	A	Schinus	204.75	4.51	1.79
November07	A	Acacia	125.50	3.02	1.39
November07	A	Casuarina	395.50	5.13	2.84
November07	A	Grevillea	216.25	3.78	1.86
November07	B	Schinus	341.25	6.56	4.68
November07	B	Acacia	268.38	6.47	4.89
November07	B	Casuarina	582.63	8.72	6.08
November07	B	Grevillea	215.38	4.61	1.87
November07	C	Schinus	358.50	7.51	5.43
November07	C	Acacia	94.52	5.32	3.29
November07	C	Casuarina	492.13	7.27	4.83
November07	C	Grevillea	241.00	4.60	2.18
December07	A	Schinus	205.88	4.51	1.80
December07	A	Acacia	127.00	3.08	1.50
December07	A	Casuarina	398.00	5.22	2.91
December07	A	Grevillea	217.75	3.81	1.88
December07	B	Schinus	342.25	6.57	4.72
December07	B	Acacia	270.88	6.57	5.08
December07	B	Casuarina	584.88	8.78	6.16
December07	B	Grevillea	215.88	4.64	1.89
December07	C	Schinus	359.50	7.53	5.45
December07	C	Acacia	196.00	5.43	3.40
December07	C	Casuarina	503.88	7.35	4.99

Plant Growth (cm). Cont'd

Month	**Block**	**Species**	**Height**	**D-base**	**D-1meter**
December07	C	Grevillea	242.63	4.62	2.19
January08	A	Schinus	206.38	4.52	1.81
January08	A	Acacia	129.00	3.17	1.62
January08	A	Casuarina	402.38	5.41	3.07
January08	A	Grevillea	219.25	3.84	1.90
January08	B	Schinus	343.00	6.58	4.77
January08	B	Acacia	273.00	6.67	4.50
January08	B	Casuarina	586.63	8.88	6.23
January08	B	Grevillea	216.50	4.65	1.91
January08	C	Schinus	360.75	7.55	5.46
January08	C	Acacia	197.88	5.76	3.52
January08	C	Casuarina	518.00	7.43	5.05
January08	C	Grevillea	244.38	4.62	2.20
February08	A	Schinus	207.50	4.53	1.82
February08	A	Acacia	131.38	3.24	1.69
February08	A	Casuarina	409.38	5.63	3.22
February08	A	Grevillea	222.13	3.87	1.92
February08	B	Schinus	344.00	6.61	3.92
February08	B	Acacia	275.00	6.76	3.85
February08	B	Casuarina	591.50	8.95	6.29
February08	B	Grevillea	219.38	4.66	1.27
February08	C	Schinus	362.63	7.57	5.47
February08	C	Acacia	199.75	5.86	3.68
February08	C	Casuarina	533.25	7.49	5.12
February08	C	Grevillea	246.25	4.65	2.21
March08	A	Schinus	208.88	4.54	1.84
March08	A	Acacia	133.13	3.28	1.77
March08	A	Casuarina	418.63	5.68	3.28
March08	A	Grevillea	224.75	3.87	2.44
March08	B	Schinus	344.75	6.57	3.93
March08	B	Acacia	277.88	6.81	3.89
March08	B	Casuarina	600.13	9.02	6.34
March08	B	Grevillea	222.13	4.68	1.19
March08	C	Schinus	363.75	7.58	5.48
March08	C	Acacia	202.75	5.97	3.76
March08	C	Casuarina	557.25	7.55	5.19
March08	C	Grevillea	248.13	4.66	2.16

Appendix III: Physical and Chemical Soil Analysis

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Sep-06	A	Acacia	0.5	0-15	7.82	951.5	0.01	0.08	0.73	30.00	4.17	3.04	2.31
Sep-06	A	Acacia	1.5	0-15	7.79	9402.0	0.01	0.08	1.11	21.50	4.17	3.48	2.31
Sep-06	A	Acacia	2.5	0-15	7.67	615.4	0.02	0.15	0.73	19.50	3.33	1.74	1.28
Sep-06	A	Acacia	0.5	15-30	7.68	1231.3	0.01	0.09	0.66	30.50	4.17	4.35	2.82
Sep-06	A	Acacia	1.5	15-30	7.84	173.1	0.01	0.07	0.95	22.50	4.17	1.30	1.79
Sep-06	A	Acacia	2.5	15-30	7.32	250.0	0.01	0.14	0.63	22.00	4.17	2.61	2.05
Sep-06	A	Acacia	0.5	30-45	7.74	173.1	0.00	0.00	0.26	32.00	4.17	3.48	2.31
Sep-06	A	Acacia	1.5	30-45	7.54	519.2	0.01	0.07	0.83	22.50	4.17	0.87	1.03
Sep-06	A	Acacia	2.5	30-45	7.81	76.9	0.02	0.17	0.70	24.50	3.33	0.87	1.28
Mar-07	A	Acacia	0.5	0-15	8.43	660.0	0.01	0.09	1.19	63.00	2.50	5.22	1.54
Mar-07	A	Acacia	1.5	0-15	8.36	723.1	0.04	0.38	1.98	63.50	2.50	5.22	1.79
Mar-07	A	Acacia	2.5	0-15	8.39	496.1	0.03	0.35	1.26	69.50	2.50	5.65	1.79
Mar-07	A	Acacia	0.5	15-30	8.40	2994.7	0.03	0.34	1.03	56.00	2.50	3.91	2.05
Mar-07	A	Acacia	1.5	15-30	8.35	748.7	0.02	0.17	1.75	73.50	3.33	5.22	1.79
Mar-07	A	Acacia	2.5	15-30	8.39	1400.0	0.02	0.16	1.44	62.00	2.50	5.65	1.54
Mar-07	A	Acacia	0.5	30-45	8.41	123.1	0.04	0.37	0.37	65.00	2.50	5.65	1.79
Mar-07	A	Acacia	1.5	30-45	8.36	3082.8	0.02	0.24	1.27	70.50	3.33	6.09	1.79
Mar-07	A	Acacia	2.5	30-45	8.36	469.1	0.01	0.13	1.36	66.00	3.33	5.22	1.54
Sep-07	A	Acacia	0.5	0-15	8.84	100.0	0.02	0.16	1.61	26.50	5.83	8.26	2.05
Sep-07	A	Acacia	1.5	0-15	8.90	1900.0	0.04	0.39	2.57	26.50	7.50	12.61	4.62
Sep-07	A	Acacia	2.5	0-15	8.52	8500.0	0.05	0.47	2.42	14.00	5.00	6.09	1.79
Sep-07	A	Acacia	2.5	15-30	8.57	1200.0	0.05	0.53	2.08	24.00	15.00	7.83	4.10
Sep-07	A	Acacia	2.5	0-15	8.52	8500.0	0.05	0.47	2.42	14.00	5.00	6.09	1.79
Sep-07	A	Acacia	2.5	15-30	8.57	1200.0	0.05	0.53	2.08	24.00	15.00	7.83	4.10
Sep-07	A	Acacia	0.5	30-45	8.90	2400.0	0.04	0.37	2.53	35.00	4.17	3.48	2.31
Sep-07	A	Acacia	1.5	30-45	8.56	7000.0	0.03	0.29	4.22	32.50	5.83	5.22	0.23
Sep-07	A	Acacia	2.5	30-45	8.44	1200.0	0.04	0.42	2.63	43.50	15.00	3.04	2.56
Mar-08	A	Acacia	0.5	0-15	7.63	1900.0	0.02	0.23	1.61	26.50	10.00	8.26	2.05
Mar-08	A	Acacia	1.5	0-15	8.37	8500.0	0.02	0.16	2.57	26.50	10.00	12.61	4.62
Mar-08	A	Acacia	2.5	0-15	8.37	135.3	0.03	0.30	2.42	14.00	10.83	6.09	1.79
Mar-08	A	Acacia	0.5	15-30	8.01	1900.0	0.03	0.29	3.18	28.00	7.50	9.13	3.59
Mar-08	A	Acacia	1.5	15-30	8.53	1200.0	0.03	0.27	3.45	30.50	10.00	11.74	3.08
Mar-08	A	Acacia	2.5	15-30	8.75	49.6	0.03	0.28	2.80	24.00	10.83	7.83	4.10
Mar-08	A	Acacia	0.5	30-45	8.23	7000.0	0.02	0.24	2.20	35.00	10.83	3.48	2.31
Mar-08	A	Acacia	1.5	30-45	8.40	1200.0	0.03	0.30	4.28	32.50	11.67	5.22	0.23
Mar-08	A	Acacia	2.5	30-45	8.67	99.2	0.03	0.27	2.65	43.50	10.00	3.04	2.56
Sep-06	A	Casuarina	0.5	0-15	7.86	176.1	0.01	0.06	0.65	23.00	5.00	2.17	3.33
Sep-06	A	Casuarina	1.5	0-15	8.30	1231.3	0.01	0.15	1.07	19.00	5.83	3.04	3.59
Sep-06	A	Casuarina	2.5	0-15	7.90	132.5	0.01	0.14	0.88	24.50	3.33	2.17	3.33
Sep-06	A	Casuarina	0.5	15-30	7.67	4141.8	0.01	0.07	1.25	19.50	4.17	3.48	3.85
Sep-06	A	Casuarina	1.5	15-30	7.82	250.0	0.02	0.15	0.77	25.00	5.83	3.04	3.59
Sep-06	A	Casuarina	2.5	15-30	7.82	615.4	0.01	0.15	0.68	26.00	4.17	0.87	3.33
Sep-06	A	Casuarina	0.5	30-45	7.90	951.5	0.01	0.14	0.88	18.50	3.33	3.04	3.59
Sep-06	A	Casuarina	1.5	30-45	7.86	250.0	0.01	0.14	0.73	25.50	4.17	2.17	3.59
Sep-06	A	Casuarina	2.5	30-45	7.93	391.8	0.02	0.19	0.53	24.00	3.33	2.17	3.59
Mar-07	A	Casuarina	1.5	15-30	8.84	568.4	0.02	0.17	1.21	54.50	7.50	1.30	1.28
Mar-07	A	Casuarina	2.5	15-30	8.90	619.6	0.01	0.13	1.55	52.00	7.50	1.74	1.79

Physical and Chemical Soil Analysis. Cont'd

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Mar-07	A	Casuarina	0.5	30-45	8.68	619.6	0.02	0.21	2.24	39.50	6.67	1.74	1.28
Mar-07	A	Casuarina	1.5	30-45	8.98	670.8	0.01	0.12	1.19	49.50	7.50	2.17	1.79
Mar-07	A	Casuarina	2.5	30-45	8.82	347.2	0.01	0.08	0.99	58.50	7.50	1.30	1.28
Sep-07	A	Casuarina	0.5	0-15	8.53	2800.0	0.02	0.21	1.23	9.50	5.00	6.52	4.10
Sep-07	A	Casuarina	1.5	0-15	8.66	2600.0	0.01	0.11	6.00	60.00	4.17	11.30	3.33
Sep-07	A	Casuarina	2.5	0-15	8.70	856.0	0.00	0.01	1.68	2.00	4.17	1.74	1.79
Sep-07	A	Casuarina	0.5	15-30	8.45	3400.0	0.02	0.25	2.52	28.00	7.50	9.13	3.85
Sep-07	A	Casuarina	1.5	15-30	8.44	9800.0	0.02	0.18	2.94	66.50	9.17	11.74	2.31
Sep-07	A	Casuarina	2.5	15-30	8.53	3700.0	0.02	0.18	1.44	52.50	5.83	9.13	2.05
Sep-07	A	Casuarina	0.5	30-45	8.56	2600.0	0.02	0.17	1.78	10.00	5.83	10.43	3.08
Sep-07	A	Casuarina	1.5	30-45	8.61	10000.0	0.02	0.24	2.13	49.50	10.00	15.65	4.10
Sep-07	A	Casuarina	2.5	30-45	8.12	3700.0	0.02	0.20	1.78	8.50	7.50	5.65	2.82
Mar-08	A	Casuarina	0.5	0-15	9.15	2600.0	0.02	0.23	5.55	9.50	3.33	6.52	4.10
Mar-08	A	Casuarina	1.5	0-15	8.85	81.0	0.03	0.28	2.32	60.00	3.33	11.30	3.33
Mar-08	A	Casuarina	2.5	0-15	8.21	1147.5	0.02	0.17	1.53	2.00	2.50	1.74	1.79
Mar-08	A	Casuarina	0.5	15-30	8.76	9800.0	0.03	0.28	4.03	28.00	3.33	9.13	3.85
Mar-08	A	Casuarina	1.5	15-30	8.36	3700.0	0.03	0.26	4.49	66.50	2.50	11.74	2.31
Mar-08	A	Casuarina	2.5	15-30	8.21	2623.0	0.02	0.20	1.44	52.50	3.33	9.13	2.05
Mar-08	A	Casuarina	0.5	30-45	8.86	1000.0	0.02	0.24	1.78	10.00	3.33	10.43	3.08
Mar-08	A	Casuarina	1.5	30-45	8.60	3700.0	0.02	0.23	2.13	49.50	4.17	15.65	4.10
Sep-06	A	Gravellia	1.5	0-15	8.32	884.6	0.00	0.00	0.49	20.50	6.67	0.87	3.59
Sep-06	A	Gravellia	2.5	0-15	8.10	346.2	0.00	0.05	0.83	9.50	4.17	0.87	2.82
Sep-06	A	Gravellia	0.5	15-30	8.01	597.0	0.01	0.09	1.36	22.00	7.50	2.61	3.85
Sep-06	A	Gravellia	1.5	15-30	8.04	423.1	0.00	0.00	0.85	21.00	5.83	2.17	4.87
Sep-06	A	Gravellia	2.5	15-30	8.19	346.2	0.01	0.05	0.95	22.50	5.83	3.48	4.87
Sep-06	A	Gravellia	0.5	30-45	8.13	615.4	0.00	0.01	0.62	21.00	6.67	2.17	3.59
Sep-06	A	Gravellia	1.5	30-45	8.06	346.2	0.03	0.29	1.02	9.50	3.33	1.30	3.85
Sep-06	A	Gravellia	2.5	30-45	8.09	692.3	0.00	0.04	0.85	9.00	3.33	0.43	2.82
Mar-07	A	Gravellia	0.5	0-15	8.56	518.2	0.00	0.05	2.50	60.00	5.00	0.87	1.54
Mar-07	A	Gravellia	1.5	0-15	8.44	1586.4	0.00	0.03	1.55	56.50	9.17	0.43	1.28
Mar-07	A	Gravellia	2.5	0-15	8.88	4867.0	0.00	0.04	2.10	60.50	10.00	0.43	1.79
Mar-07	A	Gravellia	0.5	15-30	8.52	518.2	0.00	0.03	2.94	57.00	7.50	0.87	1.28
Mar-07	A	Gravellia	1.5	15-30	8.53	5138.6	0.00	0.05	2.00	57.50	9.17	0.43	2.05
Mar-07	A	Gravellia	2.5	15-30	8.79	7957.6	0.01	0.06	1.55	65.50	10.00	0.87	1.79
Mar-07	A	Gravellia	0.5	30-45	8.57	2461.1	0.00	0.01	1.36	58.00	7.50	0.87	1.28
Mar-07	A	Gravellia	1.5	30-45	8.45	1352.6	0.00	0.00	1.71	61.50	10.83	0.87	2.31
Mar-07	A	Gravellia	2.5	30-45	8.70	710.1	0.01	0.08	1.33	68.50	9.17	0.87	2.05
Sep-07	A	Gravellia	0.5	0-15	8.57	250.0	0.02	0.23	1.70	55.00	2.50	6.52	2.56
Sep-07	A	Gravellia	1.5	0-15	8.59	3600.0	0.01	0.08	1.22	6.00	4.17	12.17	3.08
Sep-07	A	Gravellia	2.5	0-15	8.41	670.0	0.02	0.16	5.27	34.50	4.17	9.57	3.08
Sep-07	A	Gravellia	0.5	15-30	8.55	1090.0	0.01	0.09	4.23	56.50	8.33	12.17	3.85
Sep-07	A	Gravellia	1.5	15-30	8.43	760.0	0.01	0.07	2.03	24.00	3.33	10.43	3.59
Sep-07	A	Gravellia	1.5	30-45	8.40	550.0	0.01	0.07	1.75	46.50	6.67	11.30	3.33
Sep-07	A	Gravellia	2.5	30-45	8.45	300.0	0.01	0.15	4.07	45.00	3.33	6.09	1.54
Mar-08	A	Gravellia	0.5	0-15	8.36	3600.0	0.03	0.27	1.70	55.00	1.67	6.52	2.56
Mar-08	A	Gravellia	1.5	0-15	8.44	0.0	0.02	0.17	2.09	6.00	0.83	12.17	3.08
Mar-08	A	Gravellia	2.5	0-15	8.53	450.8	0.02	0.20	1.52	34.50	0.83	9.57	3.08
Mar-08	A	Gravellia	0.5	15-30	7.47	60.0	0.02	0.25	4.23	56.50	1.67	12.17	3.85
Mar-08	A	Gravellia	1.5	15-30	8.61	1800.0	0.01	0.11	2.03	24.00	0.83	10.43	3.59
Mar-08	A	Gravellia	2.5	15-30	8.12	737.7	0.02	0.18	2.42	35.00	1.67	10.87	2.82

Physical and Chemical Soil Analysis. Cont'd

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Mar-08	A	Gravellia	0.5	30-45	8.09	540.0	0.02	0.25	2.67	27.00	1.67	10.00	3.33
Mar-08	A	Gravellia	1.5	30-45	8.70	300.0	0.02	0.18	1.75	46.50	1.67	11.30	3.33
Mar-08	A	Gravellia	2.5	30-45	8.57	970.5	0.02	0.18	3.39	45.00	1.67	6.09	1.54
Sep-06	A	Schinus	0.5	0-15	7.79	597.0	0.01	0.09	1.03	32.50	5.00	1.30	3.85
Sep-06	A	Schinus	1.5	0-15	7.77	175.1	0.01	0.11	1.00	27.50	4.17	3.04	2.31
Sep-06	A	Schinus	2.5	0-15	7.66	2461.5	0.00	0.01	0.63	30.00	4.17	0.87	3.08
Sep-06	A	Schinus	0.5	15-30	7.78	579.2	0.01	0.08	0.90	31.00	5.00	0.87	3.08
Sep-06	A	Schinus	1.5	15-30	7.76	76.9	0.01	0.06	1.07	29.00	4.17	2.61	2.82
Sep-06	A	Schinus	2.5	15-30	7.72	176.1	0.01	0.06	0.73	30.00	3.33	0.87	3.08
Sep-06	A	Schinus	0.5	30-45	7.66	1044.8	0.02	0.17	0.83	27.50	4.17	0.39	2.05
Sep-06	A	Schinus	1.5	30-45	7.73	1750.7	0.00	0.00	1.00	30.00	4.17	0.87	3.85
Sep-06	A	Schinus	2.5	30-45	8.00	153.8	0.01	0.09	0.49	30.00	4.17	0.87	2.56
Sep-06	A	Schinus	0.5	0-15	8.44	146.4	0.04	0.39	0.87	59.50	2.50	1.30	2.05
Mar-07	A	Schinus	1.5	0-15	8.53	45.7	0.03	0.31	1.48	66.00	3.33	3.48	1.79
Mar-07	A	Schinus	1.5	15-30	8.12	799.6	0.03	0.32	1.73	61.50	2.50	3.48	1.54
Mar-07	A	Schinus	2.5	15-30	8.53	560.0	0.02	0.24	1.19	56.00	3.33	3.04	1.79
Mar-07	A	Schinus	0.5	30-45	8.70	401.7	0.02	0.25	1.24	59.00	1.67	1.30	2.05
Mar-07	A	Schinus	1.5	30-45	8.57	101.4	0.03	0.28	1.52	57.50	3.33	3.91	1.54
Mar-07	A	Schinus	2.5	30-45	8.59	146.4	0.02	0.18	0.87	62.00	2.50	2.61	1.54
Sep-07	A	Schinus	0.5	0-15	8.35	2060.0	0.04	0.37	1.65	25.00	5.00	39.13	1.79
Sep-07	A	Schinus	1.5	0-15	8.39	8000.0	0.04	0.35	2.44	25.50	7.50	2.17	2.56
Sep-07	A	Schinus	2.5	0-15	8.66	2400.0	0.03	0.28	1.89	40.50	5.83	6.52	2.05
Sep-07	A	Schinus	0.5	15-30	8.36	4800.0	0.04	0.35	3.04	15.00	5.83	3.48	2.56
Sep-07	A	Schinus	1.5	15-30	8.36	5000.0	0.03	0.30	1.85	39.00	5.00	8.70	1.28
Sep-07	A	Schinus	2.5	15-30	8.68	100.0	0.03	0.27	1.24	56.00	7.50	5.65	2.05
Sep-07	A	Schinus	0.5	30-45	8.39	1360.0	0.04	0.37	1.35	22.50	7.50	11.74	2.05
Sep-07	A	Schinus	1.5	30-45	8.68	1400.0	0.03	0.30	2.43	40.00	4.17	9.57	1.54
Sep-07	A	Schinus	2.5	30-45	9.10	100.0	0.02	0.23	1.97	24.50	7.50	7.39	2.56
Mar-08	A	Schinus	0.5	0-15	8.47	8000.0	0.03	0.34	2.24	25.00	2.50	39.13	1.79
Mar-08	A	Schinus	1.5	0-15	8.34	2400.0	0.05	0.51	3.27	25.50	6.67	2.17	2.56
Mar-08	A	Schinus	2.5	0-15	8.22	970.5	0.03	0.26	3.15	40.50	6.67	6.52	2.05
Mar-08	A	Schinus	0.5	15-30	8.67	5000.0	0.04	0.39	1.65	15.00	2.50	3.48	2.56
Mar-08	A	Schinus	1.5	15-30	8.15	100.0	0.05	0.48	2.36	39.00	6.67	8.70	1.28
Mar-08	A	Schinus	2.5	15-30	8.18	759.5	0.03	0.28	2.16	56.00	5.83	5.65	2.05
Mar-08	A	Schinus	0.5	30-45	7.68	1400.0	0.05	0.48	2.13	22.50	2.50	11.74	2.05
Mar-08	A	Schinus	1.5	30-45	8.01	100.0	0.03	0.26	3.69	40.00	7.50	9.57	1.54
Sep-06	B	Acacia	1.5	0-15	9.42	375.0	0.00	0.03	1.42	24.50	4.17	1.74	1.79
Sep-06	B	Acacia	2.5	0-15	9.29	675.1	0.00	0.01	1.05	27.00	4.17	1.74	1.79
Sep-06	B	Acacia	0.5	15-30	9.34	970.5	0.01	0.09	1.74	27.50	4.17	1.74	1.79
Sep-06	B	Acacia	1.5	15-30	9.46	562.5	0.01	0.05	1.01	24.50	5.00	1.74	1.79
Sep-06	B	Acacia	2.5	15-30	8.22	1392.4	0.00	0.02	1.19	27.00	5.00	1.74	2.05
Sep-06	B	Acacia	0.5	30-45	9.04	759.5	0.01	0.06	0.69	27.50	4.17	1.74	1.28
Sep-06	B	Acacia	1.5	30-45	9.82	884.6	0.00	0.04	1.46	24.50	6.67	1.74	1.79
Sep-06	B	Acacia	2.5	30-45	9.09	970.5	0.01	0.08	0.90	27.00	6.67	1.30	1.54
Sep-06	B	Acacia	0.5	0-15	9.95	853.3	0.02	0.18	0.65	83.50	11.67	1.74	2.05
Mar-07	B	Acacia	1.5	0-15	8.76	2108.9	0.01	0.15	2.81	79.00	13.33	4.35	1.79
Mar-07	B	Acacia	2.5	0-15	9.29	251.4	0.02	0.16	1.64	89.50	10.00	4.78	2.56
Mar-07	B	Acacia	0.5	15-30	9.15	980.4	0.02	0.16	2.75	79.00	14.17	2.61	1.79
Mar-07	B	Acacia	1.5	15-30	9.28	1507.0	0.00	0.01	2.89	69.50	10.00	3.04	1.54
Mar-07	B	Acacia	2.5	15-30	9.36	853.3	0.01	0.09	2.04	73.00	14.17	3.48	2.31

Physical and Chemical Soil Analysis. Cont'd

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Mar-07	B	Acacia	0.5	30-45	9.01	1012.3	0.02	0.15	2.65	73.00	8.33	1.74	1.79
Mar-07	B	Acacia	1.5	30-45	9.39	653.7	0.02	0.16	2.81	68.50	9.17	3.48	1.79
Mar-07	B	Acacia	2.5	30-45	9.29	795.8	0.01	0.09	2.64	79.00	9.17	3.04	2.31
Sep-07	B	Acacia	0.5	0-15	8.58	5100.0	0.02	0.17	2.76	52.50	3.33	12.17	2.31
Sep-07	B	Acacia	1.5	0-15	6.87	1100.0	0.01	0.12	2.57	28.50	5.00	8.70	2.05
Sep-07	B	Acacia	2.5	0-15	8.38	3900.0	0.03	0.28	2.87	50.00	10.83	13.91	1.03
Sep-07	B	Acacia	0.5	15-30	8.24	700.0	0.02	0.23	5.94	48.50	3.33	7.83	1.79
Sep-07	B	Acacia	1.5	15-30	8.34	800.0	0.03	0.27	2.30	39.00	5.00	11.30	2.82
Sep-07	B	Acacia	1.5	30-45	8.46	800.0	0.03	0.32	2.78	3.45	5.83	17.83	2.31
Sep-07	B	Acacia	2.5	30-45	8.72	900.0	0.04	0.36	1.43	67.00	7.50	14.35	2.31
Mar-08	B	Acacia	0.5	0-15	9.04	1100.0	0.02	0.23	3.01	52.50	3.33	12.17	2.31
Mar-08	B	Acacia	1.5	0-15	8.41	3900.0	0.02	0.24	2.93	28.50	8.33	8.70	2.05
Mar-08	B	Acacia	2.5	0-15	8.50	124.8	0.03	0.30	3.24	50.00	9.17	13.91	1.03
Mar-08	B	Acacia	0.5	15-30	8.99	800.0	0.02	0.23	1.68	48.50	5.00	7.83	1.79
Mar-08	B	Acacia	1.5	15-30	8.50	3800.0	0.02	0.16	2.58	39.00	5.83	11.30	2.82
Mar-08	B	Acacia	2.5	15-30	8.85	199.5	0.03	0.30	2.03	49.00	6.67	13.48	2.31
Mar-08	B	Acacia	0.5	30-45	9.00	800.0	0.03	0.29	2.43	51.50	3.33	6.96	1.54
Mar-08	B	Acacia	1.5	30-45	8.49	900.0	0.03	0.27	2.50	3.45	6.67	17.83	2.31
Mar-08	B	Acacia	2.5	30-45	8.54	251.4	0.03	0.28	2.91	67.00	5.83	14.35	2.31
Sep-06	B	Casuarina	0.5	0-15	8.78	759.5	0.02	0.16	0.58	26.00	4.17	1.30	17.95
Sep-06	B	Casuarina	1.5	0-15	8.71	379.8	0.02	0.15	0.56	27.00	4.17	1.30	1.54
Sep-06	B	Casuarina	2.5	0-15	8.33	840.2	0.01	0.15	0.67	27.00	5.00	0.43	1.28
Sep-06	B	Casuarina	0.5	15-30	8.69	942.6	0.01	0.14	0.68	25.00	4.17	0.87	1.79
Sep-06	B	Casuarina	1.5	15-30	9.34	189.9	0.01	0.14	0.67	23.00	3.33	0.87	1.28
Sep-06	B	Casuarina	2.5	15-30	8.00	942.6	0.02	0.19	0.52	24.50	4.17	0.87	2.05
Sep-06	B	Casuarina	0.5	30-45	8.85	368.9	0.01	0.15	0.58	28.00	4.17	0.43	1.03
Sep-06	B	Casuarina	1.5	30-45	8.02	464.1	0.01	0.14	0.77	23.00	3.33	0.87	1.54
Sep-06	B	Casuarina	2.5	30-45	8.57	368.9	0.02	0.15	0.77	21.50	4.17	0.30	1.03
Sep-06	B	Casuarina	0.5	0-15	9.30	1407.8	0.01	0.11	2.23	61.50	13.33	4.35	1.79
Mar-07	B	Casuarina	1.5	0-15	8.83	3491.9	0.01	0.09	0.80	61.50	7.50	1.30	1.79
Mar-07	B	Casuarina	1.5	15-30	8.84	2926.1	0.01	0.10	0.92	60.50	7.50	1.30	1.54
Mar-07	B	Casuarina	2.5	15-30	8.98	355.5	0.01	0.09	0.71	65.50	8.33	1.74	1.28
Mar-07	B	Casuarina	0.5	30-45	8.96	543.2	0.01	0.10	2.50	63.50	8.33	0.87	1.28
Mar-07	B	Casuarina	1.5	30-45	8.90	1507.0	0.01	0.13	1.19	68.50	7.50	1.30	1.54
Mar-07	B	Casuarina	2.5	30-45	9.07	598.5	0.01	0.11	1.18	66.50	8.33	1.30	1.28
Sep-07	B	Casuarina	0.5	0-15	8.83	400.0	0.02	0.19	1.17	60.00	5.00	2.61	2.05
Sep-07	B	Casuarina	1.5	0-15	8.56	3000.0	0.03	0.26	1.14	35.00	5.00	7.39	1.54
Sep-07	B	Casuarina	2.5	0-15	8.73	900.0	0.02	0.17	1.28	42.00	5.00	6.96	2.31
Sep-07	B	Casuarina	0.5	15-30	8.78	2400.0	0.04	0.41	1.33	62.50	4.17	8.26	1.79
Sep-07	B	Casuarina	1.5	15-30	8.32	400.0	0.00	0.03	1.08	19.50	5.83	6.96	1.79
Sep-07	B	Casuarina	2.5	15-30	8.83	200.0	0.02	0.16	2.22	46.50	5.00	3.04	2.05
Sep-07	B	Casuarina	0.5	30-45	8.46	2000.0	0.03	0.32	0.98	46.00	4.17	5.65	1.54
Sep-07	B	Casuarina	1.5	30-45	8.73	600.0	0.02	0.16	1.67	24.50	3.33	5.22	1.54
Sep-07	B	Casuarina	2.5	30-45	8.38	4600.0	0.02	0.17	2.22	9.00	5.83	13.04	2.05
Mar-08	B	Casuarina	0.5	0-15	8.58	3000.0	0.03	0.27	2.48	60.00	8.33	2.61	2.05
Mar-08	B	Casuarina	1.5	0-15	9.09	900.0	0.02	0.24	2.29	35.00	2.50	7.39	1.54
Mar-08	B	Casuarina	2.5	0-15	9.13	355.1	0.02	0.23	3.01	42.00	7.50	6.96	2.31
Mar-08	B	Casuarina	0.5	15-30	9.23	400.0	0.02	0.23	1.90	62.50	7.50	8.26	1.79
Mar-08	B	Casuarina	1.5	15-30	8.98	200.0	0.03	0.28	2.91	19.50	2.50	6.96	1.79
Mar-08	B	Casuarina	2.5	15-30	9.07	853.3	0.02	0.17	2.78	46.50	3.33	3.04	2.05

Physical and Chemical Soil Analysis. Cont'd

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Mar-08	B	Casuarina	0.5	30-45	9.30	600.0	0.03	0.28	4.42	46.00	1.67	5.65	1.54
Mar-08	B	Casuarina	1.5	30-45	9.98	4600.0	0.03	0.26	2.11	24.50	2.50	5.22	1.54
Sep-06	B	Gravellia	1.5	0-15	8.74	1603.4	0.01	0.08	0.58	26.00	3.33	1.74	1.54
Sep-06	B	Gravellia	2.5	0-15	8.34	5532.0	0.01	0.08	0.88	24.50	1.67	3.48	3.33
Sep-06	B	Gravellia	0.5	15-30	9.29	675.1	0.02	0.17	1.11	26.00	4.17	1.74	1.28
Sep-06	B	Gravellia	1.5	15-30	8.64	1659.8	0.01	0.12	1.01	21.50	2.50	4.35	3.08
Sep-06	B	Gravellia	2.5	15-30	9.66	423.1	0.01	0.08	0.78	25.50	1.67	3.48	2.82
Sep-06	B	Gravellia	0.5	30-45	9.18	970.5	0.01	0.15	0.64	27.00	2.50	2.61	2.31
Sep-06	B	Gravellia	1.5	30-45	8.34	2500.0	0.01	0.08	1.90	24.50	1.67	4.35	3.33
Sep-06	B	Gravellia	2.5	30-45	9.32	737.7	0.00	0.02	0.48	25.50	4.17	3.04	2.31
Sep-06	B	Gravellia	0.5	0-15	8.86	871	0.01	0.12	3.05	81.00	11.67	1.30	3.08
Mar-07	B	Gravellia	1.5	0-15	9.08	1000.9	0.01	0.09	0.92	66.50	9.17	2.61	2.31
Mar-07	B	Gravellia	2.5	0-15	9.27	710.1	0.02	0.17	1.63	71.00	5.83	3.91	2.82
Mar-07	B	Gravellia	0.5	15-30	9.02	1888.0	0.03	0.34	2.49	69.50	8.33	2.61	2.31
Mar-07	B	Gravellia	1.5	15-30	9.14	1279.3	0.03	0.26	3.03	67.50	8.33	3.04	2.31
Mar-07	B	Gravellia	2.5	15-30	9.27	1507.0	0.01	0.10	1.25	75.00	7.50	6.09	2.31
Mar-07	B	Gravellia	0.5	30-45	9.15	1092.2	0.03	0.26	5.97	70.50	18.33	2.17	2.31
Mar-07	B	Gravellia	1.5	30-45	9.14	1506.9	0.02	0.24	1.07	63.50	8.33	3.48	2.05
Mar-07	B	Gravellia	2.5	30-45	9.13	2838.1	0.02	0.17	0.83	70.50	7.50	4.78	2.82
Sep-07	B	Gravellia	0.5	0-15	8.65	8400.0	0.02	0.16	5.51	17.00	2.50	5.65	1.54
Sep-07	B	Gravellia	1.5	0-15	8.77	1700.0	0.02	0.17	1.42	61.50	5.00	13.91	2.31
Sep-07	B	Gravellia	2.5	0-15	8.96	8200.0	0.02	0.18	2.92	61.50	4.17	16.09	3.85
Sep-07	B	Gravellia	0.5	15-30	8.67	300.0	0.02	0.24	3.76	9.50	3.33	3.48	1.28
Sep-07	B	Gravellia	1.5	15-30	8.16	900.0	0.02	0.18	1.66	62.50	4.17	15.22	1.79
Sep-07	B	Gravellia	1.5	30-45	8.75	300.0	0.02	0.18	1.16	63.50	3.33	15.65	2.05
Sep-07	B	Gravellia	2.5	30-45	8.60	6600.0	0.01	0.08	1.33	68.50	25.00	7.39	1.54
Mar-08	B	Gravellia	0.5	0-15	9.41	1700.0	0.03	0.28	1.29	17.00	2.50	5.65	1.54
Mar-08	B	Gravellia	1.5	0-15	9.50	8200.0	0.02	0.25	3.28	61.50	5.00	13.91	2.31
Mar-08	B	Gravellia	2.5	0-15	9.60	122.9	0.03	0.32	2.98	61.50	7.50	16.09	3.85
Mar-08	B	Gravellia	0.5	15-30	9.94	900.0	0.03	0.27	3.24	9.50	5.00	3.48	1.28
Mar-08	B	Gravellia	1.5	15-30	9.62	500.0	0.02	0.17	4.08	62.50	5.83	15.22	1.79
Mar-08	B	Gravellia	2.5	15-30	9.32	124.8	0.03	0.27	3.72	60.50	11.67	6.09	2.82
Mar-08	B	Gravellia	0.5	30-45	9.85	300.0	0.02	0.25	3.07	66.00	4.17	20.43	2.56
Mar-08	B	Gravellia	1.5	30-45	9.80	6600.0	0.01	0.11	1.28	63.50	6.67	15.65	2.05
Mar-08	B	Gravellia	2.5	30-45	9.63	161.3	0.00	0.01	4.69	68.50	9.17	7.39	1.54
Sep-06	B	Schinus	0.5	0-15	9.29	2519.8	0.01	0.08	0.41	36.00	5.00	2.17	1.79
Sep-06	B	Schinus	1.5	0-15	8.67	87.3	0.02	0.15	0.74	24.00	2.50	2.17	3.85
Sep-06	B	Schinus	2.5	0-15	9.59	589.5	0.01	0.10	0.56	25.50	3.33	1.30	2.31
Sep-06	B	Schinus	0.5	15-30	9.33	5317.5	0.01	0.12	0.75	36.50	3.33	1.30	2.31
Sep-06	B	Schinus	1.5	15-30	8.52	1310.0	0.01	0.15	0.70	28.00	3.33	0.87	1.79
Sep-06	B	Schinus	2.5	15-30	9.38	393.0	0.01	0.09	0.35	24.50	4.17	1.30	1.54
Sep-06	B	Schinus	0.5	30-45	8.81	2777.8	0.02	0.16	0.58	22.50	2.50	1.74	2.31
Sep-06	B	Schinus	1.5	30-45	8.83	2117.9	0.00	0.03	0.84	26.50	5.00	1.74	3.08
Sep-06	B	Schinus	2.5	30-45	9.51	480.4	0.01	0.09	0.88	27.50	4.17	1.30	1.79
Sep-06	B	Schinus	0.5	0-15	9.11	124.0	0.02	0.16	4.31	61.50	7.50	0.87	4.62
Mar-07	B	Schinus	1.5	0-15	9.05	355.1	0.02	0.17	1.82	54.50	6.67	1.30	1.54
Mar-07	B	Schinus	1.5	15-30	9.15	911.9	0.00	0.02	5.43	51.50	6.67	0.87	1.54
Mar-07	B	Schinus	2.5	15-30	9.09	598.5	0.02	0.19	20.59	61.50	7.50	2.17	1.28
Mar-07	B	Schinus	0.5	30-45	9.18	1343.6	0.01	0.07	1.72	52.50	7.50	1.30	4.87
Mar-07	B	Schinus	1.5	30-45	8.93	360.0	0.02	0.23	2.66	57.50	6.67	0.43	1.54

Physical and Chemical Soil Analysis. Cont'd

Date	**Bloc**	**Species**	**dist** (m)	**depth** (cm)	**pH**	**P** (ppm)	**N** (%)	**OM** (%)	**moist** (%)	**Ca** (me%)	**Mg** (me%)	**Na** (me%)	**K** (me%)
Mar-07	B	Schinus	2.5	30-45	9.09	1279.3	0.01	0.09	1.99	82.00	9.17	3.91	1.54
Sep-07	B	Schinus	0.5	0-15	8.10	1600.0	0.00	0.05	2.48	48.50	10.00	4.78	3.33
Sep-07	B	Schinus	1.5	0-15	8.43	800.0	0.02	0.21	1.60	3.00	3.33	11.30	1.79
Sep-07	B	Schinus	2.5	0-15	8.66	200.0	0.03	0.31	1.39	4.00	4.17	4.35	1.28
Sep-07	B	Schinus	0.5	15-30	8.11	300.0	0.01	0.08	2.79	75.00	5.00	13.04	1.54
Sep-07	B	Schinus	1.5	15-30	8.40	1400.0	0.03	0.28	1.06	4.50	3.33	5.65	1.79
Sep-07	B	Schinus	2.5	15-30	8.54	1000.0	0.02	0.24	3.45	3.50	5.00	5.65	1.28
Sep-07	B	Schinus	0.5	30-45	8.56	1300.0	0.01	0.13	0.97	65.00	4.17	5.65	1.28
Sep-07	B	Schinus	1.5	30-45	8.75	1400.0	0.02	0.24	1.41	3.50	2.50	3.48	1.03
Sep-07	B	Schinus	2.5	30-45	8.58	200.0	0.04	0.40	3.99	7.50	2.50	6.09	1.54
Mar-08	B	Schinus	0.5	0-15	8.79	800.0	0.04	0.35	2.09	48.50	1.67	4.78	3.33
Mar-08	B	Schinus	1.5	0-15	8.65	200.0	0.04	0.37	2.70	3.00	2.50	11.30	1.79
Mar-08	B	Schinus	2.5	0-15	8.95	140.0	0.04	0.35	1.85	4.00	1.67	4.35	1.28
Mar-08	B	Schinus	0.5	15-30	8.85	1400.0	0.03	0.30	2.31	75.00	6.67	13.04	1.54
Mar-08	B	Schinus	1.5	15-30	8.84	1000.0	0.04	0.35	3.45	4.50	1.67	5.65	1.79
Mar-08	B	Schinus	2.5	15-30	8.97	327.7	0.02	0.24	2.54	3.50	4.17	5.65	1.28
Mar-08	B	Schinus	0.5	30-45	8.83	1400.0	0.03	0.34	3.39	65.00	2.50	5.65	1.28
Mar-08	B	Schinus	1.5	30-45	8.79	200.0	0.03	0.27	3.97	3.50	0.83	3.48	1.03
Sep-06	C	Acacia	1.5	0-15	9.57	184.4	0.02	0.17	0.30	29.00	3.33	1.30	1.28
Sep-06	C	Acacia	2.5	0-15	9.80	1987.7	0.02	0.17	0.49	35.00	4.17	1.30	1.28
Sep-06	C	Acacia	0.5	15-30	9.93	283.8	0.01	0.06	0.80	27.50	1.67	2.61	1.79
Sep-06	C	Acacia	1.5	15-30	9.55	655.7	0.00	0.04	0.63	30.00	5.00	1.30	1.03
Sep-06	C	Acacia	2.5	15-30	9.44	4701.5	0.01	0.10	0.72	43.50	4.17	1.30	1.79
Sep-06	C	Acacia	0.5	30-45	10.04	5144.9	0.01	0.08	0.82	27.50	2.50	2.61	2.31
Sep-06	C	Acacia	1.5	30-45	9.44	2745.9	0.00	0.02	0.62	32.50	3.33	0.87	1.28
Sep-06	C	Acacia	2.5	30-45	9.83	1454.9	0.02	0.17	0.70	44.00	7.50	1.30	1.54
Sep-06	C	Acacia	0.5	0-15	8.65	941.2	0.00	0.02	0.79	54.00	3.33	3.48	2.56
Mar-07	C	Acacia	1.5	0-15	8.95	941.2	0.01	0.05	0.47	59.00	4.17	2.17	2.31
Mar-07	C	Acacia	2.5	0-15	9.04	1850.8	0.00	0.03	2.19	56.50	3.33	2.17	2.56
Mar-07	C	Acacia	0.5	15-30	8.84	1031.3	0.00	0.02	1.31	57.50	4.17	2.17	5.38
Mar-07	C	Acacia	1.5	15-30	8.97	911.9	0.01	0.12	1.73	59.00	4.17	2.61	2.05
Mar-07	C	Acacia	2.5	15-30	8.99	971.6	0.00	0.03	1.93	56.50	4.17	3.04	2.82
Mar-07	C	Acacia	0.5	30-45	8.79	941.2	0.01	0.06	0.99	50.00	3.33	4.78	2.56
Mar-07	C	Acacia	1.5	30-45	9.03	736.3	0.01	0.08	1.89	55.50	39.17	2.61	2.56
Mar-07	C	Acacia	2.5	30-45	9.00	199.5	0.00	0.02	1.62	61.00	3.33	3.04	2.05
Sep-07	C	Acacia	0.5	0-15	8.64	700.0	0.04	0.38	1.61	3.50	10.00	12.17	2.82
Sep-07	C	Acacia	1.5	0-15	8.53	200.0	0.01	0.08	1.46	52.00	33.33	4.78	2.56
Sep-07	C	Acacia	2.5	0-15	8.10	2900.0	0.01	0.08	3.72	45.00	4.17	4.78	1.79
Sep-07	C	Acacia	0.5	15-30	8.56	3400.0	0.02	0.17	4.48	3.00	1.67	13.48	5.38
Sep-07	C	Acacia	1.5	15-30	8.66	300.0	0.01	0.15	1.40	3.00	3.33	8.26	3.08
Sep-07	C	Acacia	1.5	30-45	8.36	2900.0	0.02	0.19	3.48	54.00	9.17	6.09	1.79
Sep-07	C	Acacia	2.5	30-45	8.24	600.0	0.00	0.02	2.08	25.00	1.67	13.48	1.54
Mar-08	C	Acacia	0.5	0-15	8.39	200.0	0.01	0.15	1.26	3.50	6.67	12.17	2.82
Mar-08	C	Acacia	1.5	0-15	8.68	2900.0	0.01	0.14	1.39	52.00	4.17	4.78	2.56
Mar-08	C	Acacia	2.5	0-15	9.10	10900.0	0.02	0.15	1.10	45.00	4.17	4.78	1.79
Mar-08	C	Acacia	0.5	15-30	8.39	300.0	0.02	0.15	1.59	3.00	4.17	13.48	5.38
Mar-08	C	Acacia	1.5	15-30	8.66	800.0	0.02	0.18	1.13	3.00	5.00	8.26	3.08
Mar-08	C	Acacia	2.5	15-30	8.84	3300.0	0.02	0.21	1.72	30.00	5.83	12.17	1.79
Mar-08	C	Acacia	0.5	30-45	8.36	2900.0	0.01	0.13	2.19	51.50	9.17	9.13	2.56
Mar-08	C	Acacia	1.5	30-45	8.68	600.0	0.02	0.18	1.70	54.00	5.00	6.09	1.79

Physical and Chemical Soil Analysis. Cont'd

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Mar-08	C	Acacia	2.5	30-45	8.98	900.0	0.01	0.14	1.29	25.00	5.83	13.48	1.54
Sep-06	C	Casuarina	0.5	0-15	9.65	1269.2	0.00	0.05	0.67	45.50	2.50	1.30	2.56
Sep-06	C	Casuarina	1.5	0-15	9.76	692.3	0.01	0.09	0.90	38.50	2.50	2.17	2.05
Sep-06	C	Casuarina	2.5	0-15	9.75	196.5	0.01	0.05	0.49	37.50	2.50	2.17	2.82
Sep-06	C	Casuarina	0.5	15-30	9.02	1558.0	0.01	0.13	0.52	42.50	2.50	3.91	2.82
Sep-06	C	Casuarina	1.5	15-30	9.22	858.2	0.01	0.08	0.96	39.50	5.00	3.04	2.31
Sep-06	C	Casuarina	2.5	15-30	8.23	266.4	0.00	0.04	0.49	37.50	2.50	2.17	2.82
Sep-06	C	Casuarina	0.5	30-45	9.14	1666.7	0.01	0.08	0.61	40.50	4.17	2.61	2.05
Sep-06	C	Casuarina	1.5	30-45	9.72	1956.5	0.01	0.09	0.64	38.00	4.17	3.04	2.31
Sep-06	C	Casuarina	2.5	30-45	9.52	398.6	0.01	0.08	0.45	38.50	4.17	2.17	2.31
Mar-07	C	Casuarina	0.5	0-15	8.41	329.1	0.01	0.08	1.10	50.50	5.00	3.48	2.31
Mar-07	C	Casuarina	1.5	0-15	8.50	408.0	0.00	0.05	1.35	57.00	3.33	3.48	2.56
Mar-07	C	Casuarina	1.5	15-30	8.85	199.5	0.01	0.08	1.47	57.00	3.33	3.04	2.56
Mar-07	C	Casuarina	2.5	15-30	9.23	99.2	0.01	0.06	0.71	51.50	4.17	2.17	2.31
Mar-07	C	Casuarina	0.5	30-45	8.49	355.1	0.00	0.05	0.94	51.00	4.17	3.48	2.31
Mar-07	C	Casuarina	1.5	30-45	8.54	277.3	0.01	0.08	1.14	58.00	5.00	6.09	2.56
Mar-07	C	Casuarina	2.5	30-45	9.30	738.3	0.01	0.06	0.69	52.00	4.17	2.61	2.31
Sep-07	C	Casuarina	0.5	0-15	8.08	200.0	0.02	0.17	1.02	34.50	3.33	7.83	1.03
Sep-07	C	Casuarina	1.5	0-15	8.28	400.0	0.02	0.15	1.60	29.50	10.00	5.22	3.08
Sep-07	C	Casuarina	2.5	0-15	8.32	900.0	0.01	0.10	1.20	34.00	3.33	15.22	2.05
Sep-07	C	Casuarina	0.5	15-30	8.57	1000.0	0.01	0.12	0.78	72.00	2.50	8.70	1.28
Sep-07	C	Casuarina	1.5	15-30	8.57	200.0	0.01	0.15	2.59	35.50	4.17	2.61	1.79
Sep-07	C	Casuarina	2.5	15-30	8.30	320.0	0.01	0.09	1.39	32.00	15.00	3.04	5.13
Sep-07	C	Casuarina	0.5	30-45	8.53	200.0	0.02	0.16	2.54	20.50	10.00	15.65	3.08
Sep-07	C	Casuarina	1.5	30-45	8.51	300.0	0.03	0.34	2.70	33.00	23.33	12.61	3.08
Sep-07	C	Casuarina	2.5	30-45	8.30	210.0	0.01	0.09	0.78	14.50	10.83	11.30	1.54
Mar-08	C	Casuarina	0.5	0-15	8.90	400.0	0.02	0.17	1.07	34.50	6.67	7.83	1.03
Mar-08	C	Casuarina	1.5	0-15	8.56	900.0	0.01	0.15	1.53	29.50	6.67	5.22	3.08
Mar-08	C	Casuarina	2.5	0-15	8.44	329.1	0.01	0.14	1.76	34.00	5.83	15.22	2.05
Mar-08	C	Casuarina	0.5	15-30	8.90	200.0	0.02	0.16	2.42	72.00	5.83	8.70	1.28
Mar-08	C	Casuarina	1.5	15-30	8.52	0.0	0.02	0.15	1.71	35.50	5.83	2.61	1.79
Mar-08	C	Casuarina	2.5	15-30	8.53	49.6	0.01	0.15	1.40	32.00	4.17	3.04	5.13
Mar-08	C	Casuarina	0.5	30-45	8.82	300.0	0.01	0.14	2.01	20.50	6.67	15.65	3.08
Mar-08	C	Casuarina	1.5	30-45	8.57	0.0	0.01	0.14	1.67	33.00	11.67	12.61	3.08
Sep-07	A	Acacia	2.5	15-30	8.57	1200.0	0.05	0.53	2.08	24.00	15.00	7.83	4.10
Sep-07	A	Acacia	0.5	30-45	8.90	2400.0	0.04	0.37	2.53	35.00	4.17	3.48	2.31
Sep-06	C	Gravellia	1.5	0-15	9.94	786.0	0.01	0.12	0.70	39.50	2.50	2.61	2.31
Sep-06	C	Gravellia	2.5	0-15	9.45	82.0	0.01	0.09	0.32	37.50	3.33	2.61	3.08
Sep-06	C	Gravellia	0.5	15-30	9.94	480.4	0.02	0.23	0.50	37.50	2.50	2.17	3.08
Sep-06	C	Gravellia	1.5	15-30	9.54	1161.7	0.01	0.08	1.28	37.00	2.50	4.78	3.33
Sep-06	C	Gravellia	2.5	15-30	9.53	346.2	0.01	0.09	0.72	36.50	3.33	2.17	2.82
Sep-06	C	Gravellia	0.5	30-45	9.95	489.1	0.01	0.09	0.32	38.50	2.50	1.74	2.82
Sep-06	C	Gravellia	1.5	30-45	9.95	2644.9	0.01	0.09	1.28	38.50	2.50	3.91	2.82
Sep-06	C	Gravellia	2.5	30-45	9.88	692.3	0.01	0.12	0.72	36.00	2.50	2.61	2.31
Mar-07	C	Gravellia	0.5	0-15	9.09	49.6	0.01	0.06	0.90	54.00	4.17	6.52	2.31
Mar-07	C	Gravellia	1.5	0-15	9.13	853.3	0.01	0.08	2.48	54.50	4.17	6.09	2.05
Mar-07	C	Gravellia	2.5	0-15	9.41	823.9	0.01	0.06	0.48	64.00	5.83	4.35	2.05
Mar-07	C	Gravellia	0.5	15-30	8.98	49.6	0.01	0.07	0.89	54.50	4.17	6.52	2.31
Mar-07	C	Gravellia	1.5	15-30	9.07	795.8	0.01	0.09	2.09	51.00	3.33	4.78	2.31
Mar-07	C	Gravellia	2.5	15-30	9.94	830.1	0.01	0.08	16.03	61.50	6.67	5.65	1.79

Physical and Chemical Soil Analysis. Cont'd

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Mar-07	C	Gravellia	0.5	30-45	9.98	148.8	0.01	0.08	0.46	54.00	4.17	6.09	2.31
Mar-07	C	Gravellia	1.5	30-45	9.11	1407.8	0.01	0.11	4.10	53.00	3.33	4.35	2.31
Mar-07	C	Gravellia	2.5	30-45	9.85	303.2	0.01	0.09	1.34	63.00	5.00	3.48	1.79
Sep-07	C	Gravellia	0.5	0-15	8.19	200.0	0.02	0.18	2.57	16.00	11.67	10.87	3.08
Sep-07	C	Gravellia	1.5	0-15	8.68	300.0	0.00	0.03	4.52	27.00	5.00	4.78	3.59
Sep-07	C	Gravellia	2.5	0-15	8.55	6600.0	0.00	0.01	1.45	3.50	5.00	4.78	2.05
Sep-07	C	Gravellia	0.5	15-30	8.33	1700.0	0.02	0.21	1.38	26.00	6.67	5.65	2.31
Sep-07	C	Gravellia	1.5	15-30	8.61	8200.0	0.01	0.05	2.71	29.50	5.00	10.43	2.31
Sep-07	C	Gravellia	1.5	30-45	8.36	500.0	0.00	0.04	2.26	63.00	9.17	6.09	7.18
Sep-07	C	Gravellia	2.5	30-45	8.34	1600.0	0.01	0.08	1.24	2.00	5.83	10.87	3.08
Mar-08	C	Gravellia	0.5	0-15	8.88	300.0	0.02	0.15	1.26	16.00	12.50	10.87	3.08
Mar-08	C	Gravellia	1.5	0-15	8.81	6600.0	0.02	0.17	1.36	27.00	11.67	4.78	3.59
Mar-08	C	Gravellia	2.5	0-15	8.93	942.6	0.01	0.15	0.73	3.50	8.33	4.78	2.05
Mar-08	C	Gravellia	0.5	15-30	8.79	8200.0	0.02	0.21	1.75	26.00	12.50	5.65	2.31
Mar-08	C	Gravellia	1.5	15-30	8.72	300.0	0.04	0.38	1.19	29.50	9.17	10.43	2.31
Mar-08	C	Gravellia	2.5	15-30	8.82	737.7	0.01	0.12	2.00	3.00	10.83	5.65	1.79
Mar-08	C	Gravellia	0.5	30-45	8.70	500.0	0.01	0.14	1.34	24.50	11.67	6.52	1.79
Mar-08	C	Gravellia	1.5	30-45	8.89	1600.0	0.02	0.17	1.36	63.00	8.33	6.09	7.18
Mar-08	C	Gravellia	2.5	30-45	8.72	994.5	0.02	0.16	2.47	2.00	6.67	10.87	3.08
Sep-06	C	Schinus	0.5	0-15	9.50	2519.8	0.01	0.08	0.74	24.50	2.50	2.17	3.08
Sep-06	C	Schinus	1.5	0-15	9.60	87.3	0.01	0.08	0.72	24.50	2.50	1.74	2.82
Sep-06	C	Schinus	2.5	0-15	9.63	589.5	0.02	0.17	1.20	26.50	1.67	2.61	3.33
Sep-06	C	Schinus	0.5	15-30	9.62	5317.5	0.00	0.04	0.97	24.00	2.50	1.74	3.08
Sep-06	C	Schinus	1.5	15-30	9.32	1310.0	0.00	0.03	1.00	24.00	1.67	1.74	2.82
Sep-06	C	Schinus	2.5	15-30	9.55	393.0	0.02	0.16	0.86	27.50	2.50	2.17	2.82
Sep-06	C	Schinus	0.5	30-45	9.80	2777.8	0.01	0.09	1.16	22.50	1.67	1.74	2.82
Sep-06	C	Schinus	1.5	30-45	9.63	2117.9	0.02	0.16	0.99	24.50	2.50	1.74	2.82
Sep-06	C	Schinus	2.5	30-45	9.49	480.4	0.02	0.17	0.79	26.00	1.67	2.17	2.56
Mar-07	C	Schinus	0.5	0-15	8.81	9716.0	0.01	0.07	2.48	56.50	8.33	4.35	3.08
Mar-07	C	Schinus	1.5	0-15	8.93	8239.4	0.01	0.10	1.06	61.50	4.17	1.74	2.56
Mar-07	C	Schinus	1.5	15-30	8.82	4933.6	0.01	0.05	1.73	68.50	3.33	1.30	2.31
Mar-07	C	Schinus	2.5	15-30	8.85	5353.9	0.00	0.03	1.46	63.50	3.33	1.74	2.56
Mar-07	C	Schinus	0.5	30-45	8.89	882.6	0.01	0.08	2.48	61.00	3.33	1.74	2.82
Mar-07	C	Schinus	1.5	30-45	8.72	5578.2	0.01	0.08	1.88	65.50	4.17	1.74	2.31
Mar-07	C	Schinus	2.5	30-45	8.83	911.9	0.01	0.08	1.78	69.50	3.33	1.74	2.31
Sep-07	C	Schinus	0.5	0-15	8.37	100.0	0.02	0.15	2.06	49.00	4.17	10.00	2.05
Sep-07	C	Schinus	1.5	0-15	8.52	200.0	0.01	0.15	2.06	42.50	33.33	7.39	1.54
Sep-07	C	Schinus	2.5	0-15	8.12	300.0	0.02	0.21	2.30	26.00	3.33	8.26	1.79
Sep-07	C	Schinus	0.5	15-30	8.33	1100.0	0.01	0.14	3.24	57.50	12.50	22.17	5.90
Sep-07	C	Schinus	1.5	15-30	8.44	100.0	0.02	0.19	1.71	40.00	3.33	9.13	2.31
Sep-07	C	Schinus	2.5	15-30	8.55	300.0	0.01	0.14	2.26	24.50	9.17	6.09	1.54
Sep-07	C	Schinus	0.5	30-45	8.48	2400.0	0.01	0.14	2.24	35.00	7.50	3.48	2.05
Sep-07	C	Schinus	1.5	30-45	8.39	150.0	0.02	0.15	2.03	35.50	33.33	4.78	2.31
Sep-07	C	Schinus	2.5	30-45	8.70	100.0	0.02	0.17	1.28	29.50	4.17	4.78	2.56
Mar-08	C	Schinus	0.5	0-15	8.55	200.0	0.02	0.20	1.38	49.00	8.33	10.00	2.05
Mar-08	C	Schinus	1.5	0-15	8.43	300.0	0.02	0.21	1.66	42.50	3.33	7.39	1.54
Mar-08	C	Schinus	2.5	0-15	8.36	13400.0	0.02	0.24	1.18	26.00	3.33	8.26	1.79
Mar-08	C	Schinus	0.5	15-30	8.53	120.0	0.02	0.23	2.95	57.50	1.67	22.17	5.90
Mar-08	C	Schinus	1.5	15-30	8.40	300.0	0.02	0.24	2.57	40.00	2.50	9.13	2.31
Mar-08	C	Schinus	2.5	15-30	8.35	2600.0	0.02	0.23	1.48	24.50	3.33	6.09	1.54

Physical and Chemical Soil Analysis. Cont'd

Date	Bloc	Species	dist (m)	depth (cm)	pH	P (ppm)	N (%)	OM (%)	moist (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Mar-08	C	Schinus	0.5	30-45	8.59	110.0	0.02	0.21	2.12	35.00	3.33	3.48	2.05
Mar-08	C	Schinus	1.5	30-45	8.41	100.0	0.02	0.24	1.82	35.50	3.33	4.78	2.31
Sep-06	D	Control		0-15	8.55	737.7	0.01	0.05	0.83	22.50	1.67	1.74	1.03
Sep-06	D	Control		0-15	8.09	2623.0	0.00	0.02	0.94	22.50	1.67	4.78	2.82
Sep-06	D	Control		0-15	8.89	737.7	0.00	0.00	1.29	23.00	4.17	3.91	2.31
Sep-06	D	Control		0-15	9.13	759.5	0.00	0.00	1.03	23.50	5.00	3.04	3.08
Sep-06	D	Control		0-15	9.37	1250.0	0.01	0.05	1.00	24.00	4.17	4.78	2.31
Sep-06	D	Control		0-15	8.28	82.0	0.00	0.00	0.74	26.50	5.00	3.91	2.31
Sep-06	D	Control		0-15	9.53	2151.9	0.00	0.00	0.73	23.00	7.50	2.61	2.56
Sep-06	D	Control		0-15	9.47	1075.9	0.00	0.00	1.27	27.00	5.00	3.91	2.31
Sep-06	D	Control		0-15	9.21	1181.4	0.01	0.08	0.73	21.00	2.50	1.30	1.28
Sep-06	D	Control		15-30	8.83	1454.9	0.00	0.03	0.91	22.00	1.67	1.74	1.28
Sep-06	D	Control		15-30	8.81	994.5	0.00	0.04	1.39	22.50	1.67	1.74	2.05
Sep-06	D	Control		15-30	8.52	1181.4	0.00	0.01	1.13	23.00	1.67	4.35	2.56
Sep-06	D	Control		15-30	8.73	970.5	0.00	0.02	1.20	24.50	5.00	3.91	2.82
Sep-06	D	Control		15-30	9.10	387.3	0.00	0.03	0.90	23.50	4.17	3.48	3.08
Sep-06	D	Control		15-30	8.79	450.8	0.00	0.01	1.07	24.50	4.17	4.78	2.31
Sep-06	D	Control		15-30	7.79	184.4	0.00	0.00	0.73	24.50	2.50	3.91	2.31
Sep-06	D	Control		15-30	8.89	1814.4	0.00	0.05	0.66	23.00	3.33	4.78	1.03
Sep-06	D	Control		15-30	9.37	1054.9	0.00	0.00	1.16	24.50	5.00	3.91	2.31
Sep-06	D	Control		15-30	9.19	1497.9	0.01	0.07	1.29	24.50	2.50	1.74	1.54
Sep-06	D	Control		30-45	9.07	942.6	0.00	0.03	0.79	22.50	1.67	1.74	1.28
Sep-06	D	Control		30-45	8.83	1147.5	0.00	0.01	1.26	22.50	1.67	1.74	1.79
Sep-06	D	Control		30-45	8.78	450.8	0.00	0.01	0.57	23.50	3.33	3.04	2.05
Sep-06	D	Control		30-45	8.81	970.5	0.00	0.01	1.00	25.00	5.00	3.91	1.28
Mar-07	D	Control		30-45	8.85	251.4	0.00	0.01	0.26	82.00	9.17	5.22	2.05
Mar-07	D	Control		30-45	9.39	135.3	0.00	0.03	0.83	59.00	10.00	4.78	2.56
Mar-07	D	Control		30-45	9.51	355.1	0.00	0.01	1.65	37.00	9.17	5.22	1.79
Mar-07	D	Control		30-45	9.45	22.9	0.00	0.01	1.39	58.00	11.67	3.48	1.54
Mar-07	D	Control		30-45	9.36	10.0	0.00	0.00	0.73	55.50	10.00	3.91	2.05
Mar-07	D	Control		30-45	9.09	124.8	0.00	0.00	1.67	54.50	7.50	3.48	2.31
Mar-07	D	Control		30-45	8.66	68.7	0.00	0.04	1.01	55.50	7.50	3.91	1.28
Mar-07	D	Control		0-15	8.47	1147.5	0.01	0.07	1.18	59.00	7.50	4.35	2.05
Mar-07	D	Control		0-15	8.34	450.8	0.01	0.10	1.53	37.00	7.50	5.22	2.31
Mar-07	D	Control		0-15	8.22	970.5	0.01	0.08	1.07	58.00	9.17	5.22	2.31
Mar-07	D	Control		0-15	7.63	135.3	0.00	0.02	0.88	55.50	6.67	3.04	2.31
Mar-07	D	Control		0-15	8.37	355.1	0.01	0.05	1.18	54.50	13.33	4.35	2.31
Mar-07	D	Control		0-15	8.37	22.9	0.00	0.03	1.12	58.00	12.50	4.78	1.79
Mar-07	D	Control		0-15	9.15	10.0	0.01	0.08	1.27	52.00	12.50	3.48	2.82
Mar-07	D	Control		0-15	8.85	124.8	0.00	0.05	1.16	54.00	9.17	6.96	2.31
Mar-07	D	Control		0-15	8.21	329.1	0.01	0.08	1.40	53.00	10.00	6.52	2.31
Mar-07	D	Control		0-15	8.36	942.6	0.00	0.00	1.25	82.00	5.83	3.48	1.54
Mar-07	D	Control		15-30	8.67	2623.0	0.01	0.08	1.42	61.00	5.83	5.22	1.54
Sep-07	D	Control		15-30	8.01	49.6	0.00	0.02	0.95	51.50	10.00	3.91	2.05
Sep-07	D	Control		15-30	8.53	853.3	0.00	0.04	1.42	57.00	12.50	3.04	2.05
Sep-07	D	Control		15-30	8.75	124.8	0.00	0.03	1.41	55.00	12.50	3.48	3.08
Sep-07	D	Control		15-30	8.76	327.7	0.01	0.12	1.34	54.00	12.50	5.22	2.56
Sep-07	D	Control		15-30	8.36	199.5	0.01	0.08	0.59	54.50	7.50	6.52	2.56
Sep-07	D	Control		15-30	8.21	49.6	0.00	0.02	1.07	64.00	7.50	6.52	2.56
Sep-07	D	Control		15-30	7.47	737.7	0.00	0.03	1.18	67.00	7.50	3.48	1.28

Physical and Chemical Soil Analysis. Cont'd

Date	**Bloc**	**Species**	**dist** (m)	**depth** (cm)	**pH**	**P** (ppm)	**N** (%)	**OM** (%)	**moist** (%)	**Ca** (me%)	**Mg** (me%)	**Na** (me%)	**K** (me%)
Sep-07	D	Control		30-45	7.68	1181.4	0.01	0.08	1.58	35.50	6.67	4.78	2.05
Sep-07	D	Control		30-45	8.01	970.5	0.01	0.08	1.39	61.50	10.00	5.22	2.31
Sep-07	D	Control		30-45	8.12	387.3	0.01	0.08	0.73	56.00	7.50	3.48	2.31
Sep-07	D	Control		30-45	8.23	99.2	0.01	0.06	1.65	51.50	11.67	3.91	2.31
Sep-07	D	Control		30-45	8.40	20.0	0.00	0.02	1.48	57.00	11.67	3.48	1.79
Sep-07	D	Control		30-45	8.67	161.3	0.00	0.02	1.87	51.50	11.67	3.91	3.08
Sep-07	D	Control		30-45	8.86	303.8	0.00	0.05	1.55	54.50	9.17	6.09	2.31
Sep-07	D	Control		30-45	8.60	251.4	0.01	0.08	0.68	51.00	10.00	6.09	2.56
Sep-07	D	Control		30-45	8.44	135.3	0.00	0.01	1.24	61.50	10.00	6.09	2.56
Sep-07	D	Control		30-45	8.09	994.5	0.00	0.03	1.51	62.00	7.50	5.22	1.54
Sep-07	D	Control		0-15	9.63	4800.0	0.02	0.18	1.24	59.00	9.17	4.35	2.05
Sep-07	D	Control		0-15	9.75	5200.0	0.01	0.06	1.71	37.00	7.50	5.22	2.31
Sep-07	D	Control		0-15	9.57	2400.0	0.01	0.08	1.27	58.00	9.17	5.22	2.31
Sep-07	D	Control		0-15	9.80	300.0	0.01	0.05	1.16	55.50	6.67	3.04	2.31
Sep-07	D	Control		0-15	9.65	300.0	0.00	0.03	1.40	54.50	8.33	4.35	2.31
Sep-07	D	Control		0-15	9.80	1700.0	0.00	0.03	1.11	54.00	5.83	6.96	2.31
Sep-07	D	Control		0-15	9.63	1100.0	0.01	0.12	1.34	53.00	8.33	6.52	2.31
Sep-07	D	Control		0-15	9.49	3400.0	0.01	0.08	1.96	82.00	5.83	3.48	1.54
Sep-07	D	Control		15-30	9.55	13600.0	0.00	0.00	1.55	61.00	9.17	5.22	1.54
Sep-07	D	Control		15-30	9.93	2400.0	0.01	0.08	1.91	36.00	9.17	5.22	2.05
Sep-07	D	Control		15-30	9.55	2000.0	0.01	0.08	2.34	60.50	7.50	3.48	2.31
Sep-07	D	Control		15-30	9.44	200.0	0.01	0.08	0.59	51.50	6.67	3.91	2.05
Sep-07	D	Control		15-30	9.02	1300.0	0.01	0.08	1.07	57.00	10.00	3.04	2.05
Sep-07	D	Control		15-30	9.22	4000.0	0.01	0.06	1.18	55.00	10.00	3.48	3.08
Sep-07	D	Control		15-30	9.50	200.0	0.00	0.02	1.48	54.00	6.67	5.22	2.56
Sep-07	D	Control		15-30	9.60	900.0	0.00	0.02	1.87	54.50	7.50	6.52	2.56
Mar-08	D	Control		15-30	9.63	2400.0	0.00	0.05	1.04	64.00	5.83	6.52	2.56
Mar-08	D	Control		15-30	9.75	2200.0	0.00	0.00	0.68	67.00	5.00	3.48	1.28
Mar-08	D	Control		30-45	9.49	6600.0	0.00	0.04	1.62	35.50	9.17	4.78	2.05
Mar-08	D	Control		30-45	10.04	300.0	0.01	0.07	1.87	61.50	9.17	5.22	2.31
Mar-08	D	Control		30-45	9.44	135.3	0.00	0.00	1.55	56.00	6.67	3.48	2.31
Mar-08	D	Control		30-45	9.83	355.1	0.01	0.08	0.68	51.50	10.00	3.91	2.31
Mar-08	D	Control		30-45	9.14	22.9	0.00	0.02	1.24	57.00	9.17	3.48	1.79
Mar-08	D	Control		30-45	9.72	10.0	0.01	0.05	1.51	51.50	10.00	3.91	3.08
Mar-08	D	Control		30-45	9.62	124.8	0.00	0.03	1.71	54.50	6.67	6.09	2.31
Mar-08	D	Control		30-45	9.32	68.7	0.00	0.00	0.86	51.00	7.50	6.09	2.56
Mar-08	D	Control		30-45	9.55	135.3	0.00	0.05	1.16	61.50	6.67	6.09	2.56
Mar-08	D	Control		30-45	9.93	355.1	0.01	0.08	1.96	62.00	7.50	5.22	1.54