MIDLANDS STATE UNIVERSITY

COMPARATIVE STUDY ON EARLY GROWTH PERFORMANCE OF *DODONAEA VISCOSA* AND *LEUCAENA LEUCOCEPHALA* PLANTED ON DIFFERENT SOIL TYPES APPLIED ON MINE TAILINGS DUMP AT RENCO MINE

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APPROVAL FORM

I **R104936R**, certify that this dissertation is the product of my original work and has been prepared in accordance with the guidelines of he Master in Safety, Health and Environmental Management Degree programme, Midlands State University. I further attest that this work has not been submitted in part or in full for any other degree at any University.

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DEDICATION

To my lovely daughter, Brielle Shemakanaka, God richly bless you.

ACKNOWLEDGEMENTS

ABSTRACT

Renco Mine tailings dump was commissioned in 1998, since 2006, a few tolerant plant species, most often exotics, with lower growth rates and not acclimatized to local conditions were once planted on the tailings dump using natural soil in an attempt to reclaim it. The main objective of the study was to compare early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* planted on biosolids (treatment) and natural soil (control) applied on an operational mine tailings dump at Renco Mine, Zimbabwe. Soil fertility analysis results shown that, both soils were very acidic, high in N and had traces of Ca, Mg and K. However, only boisoilds were high in P. Two rows with 125 planting holes each and an inter-row spacing of 2m were established on grass covered block area, and similarly on bare ground block area, and half of the holes randomly applied with either of the soil types in each block. A total of 250 *Dodonaea viscosa* species and 250 *Leucaena leucocephala* species were randomly planted on these planting stations in December 2017. Generally, *Dodonaea viscosa* planted on biosolids on grass covered area exhibited the highest overall monthly growth height increment interval of 3.1 ± 1.45cm. Similarly, *Leucaena leucocephala* recorded an overall monthly mean height growth increment interval of 2.27 ± 1.11cm. The highest monthly average Root Collar Diameter intervals were 0.03 ± 0.02cm on both species planted on biosolids with grass cover. *Dodonaea viscosa* planted on biosolids soil treatment on grass covered ground recorded the highest survival rate of 66.7%. *Leucaena leucocephala* planted on biosolids soil treatment on grass covered ground recorded its highest survival rate of 61.1%. Lowest survival rates were recorded on *Leucaena leucocephala* planted on natural soil on both bare ground and grass covered with survival rates of 22.2% and 33.3% respectively. Significant differences were observed in early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* on mine tailings dump ($P<0.05$). Similarly, significant differences were observed in early growth performance of *species* on different soil treatments applied on mine tailings dump ($P<0.05$) as well as early growth performance of *species* on grass covered soil and bare soil on mine tailings dump ($P<0.05$). Findings of the study indicate that, *Dodonaea viscosa* can be extensively used in revegetation of mine dumps, while *Leucaena leucocephala* can be relatively used with ameliorative measures on pH.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The mining sector in Zimbabwe has significantly flourished over the years with an average growth of 3.5% (Chamber of Mines, 2015). The World Bank has projected an increase on value of minerals from $2.1 billion to an average of around $8 billion by 2018 (Chamber of Mines, 2015). Chamber of Mines (2015) added that, mining sector has contributed 15% of nominal GDP, 58% of the nation's total exports, 13% of fiscal revenue, more than 45000 employment jobs, and more than 50% of foreign direct investment. This implies that, extraction of minerals bear meaningful socio-economic benefits, for that reason, certainly exploitation of minerals is necessary for economic development. However, Singh (2015) indicated that, environmental impacts at mines are generally large, with total destruction of the vegetation on mined areas, and considerable reshaping of the natural topography. For instance, the establishment of tailings dumps facilities and disposal of tailings changes the form of fringe ecosystems.

In relation to that, Singh (2015) indicated that, where tailings dump construction takes place, the land is usually cleared of all vegetation, the landscape drastically altered and the ecosystem totally disrupted. Bell (1998) noted that, if inappropriately managed, such activities can also have significant off-site impacts, particularly from the discharge of drainage contaminated with sediments, chemicals, metals or altered acidity. These dumps are drastically disturbed and are physically, nutritionally and microbiologically impoverished habitats (Singh and Jha, 1993). Similarly, Blight (1989) stated that, tailings dams cause additional environmental impacts if they are not vegetated and stabilized because heavy rains can easily wash away the unstable dams into streams, rivers and lakes. Sediments in streams and lakes have negative impacts such as increasing water temperatures, which lowers the concentration of dissolved oxygen. This in turn can kill fish and other aquatic organisms, and finally disrupt food chains. Gorman (2004) indicated that, sediment destroys spawning beds and destructs lakes and streams from scenic beauty and recreational uses. Gorman (2004) added that, sedimentation increases flooding because it reduces a stream's water carrying capacity after overflows the banks more easily, flooding the surrounding settlements thereby triggering social, economical and environmental damage.

According to Singh (2015), the disposal of mine tailings is one of major environmental issues that have become more serious with the increasing exploration for minerals. In relation to this, Bell (1998) mentioned that, mine wastes represent the highest proportion of waste produced by industrial activity, with billions of tonnes being produced annually. In general, Guoqing et al. (2017) mentioned that, mining activities can give rise to vegetation deterioration, soil erosion, geological hazards and environmental pollution, which restrict the sustainable development of mining areas. In light to that, Guoqing et al. (2017) added that mining areas are thus a typical vulnerable ecosystem.

Legally, Section 73 (1) (b) (i) of the Constitution of Zimbabwe Amendment (No. 20) Act (2013) prescribes that, every person has a right to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation. In line with that, Section 4 (2) (f) of the Environmental Management Act (20:27) as read with Section 24(1)(a) of S.I. 6 of 2007 prescribes that, anticipated negative impact on the environment and on people's environmental rights shall be prevented, and where they cannot be altogether prevented be minimized and remedied. To that end, requirements related to rehabilitation of tailings dumps facilities have to be complied with.

Mulizane et al. (2005) suggested that, initiating the normal ecological succession using less-cost techniques is the preferred strategy on mine tailings dumps rehabilitation, such that, in terms of biodiversity, the environment can then enrich itself natural, as plants and animals wildlife can be progressively restored. In agreement with that, Baker and Brooks (1989) stated that, the first step which can only be considered in building up a self-sustaining ecosystem is through re-vegetation by plants, and colonization by microorganisms, birds and insects is necessary before the system can be considered viable. In line with this, Sheoran and Poonia (2010) suggested that, once the abandoned mine lands have vegetation growing on the surface, regeneration of these areas for productive use will begin and offsite damages will be minimized. These opinions are most ideal for tailings dumps rehabilitation.

However, Troung (1999) indicated that, tailings materials mainly consist of crushed rock, with poor physical structure, less moisture content, metal toxicity, acid generating on the surface, high salt concentrations and lack essential nutrients for plant growth. Stanley et al. (2000) pointed out that, tailings materials are inappropriate for plant growth, as a result there is need to assess the

performance of different species in re-vegetating tailings dams. For that reason, Swann (2007) suggested that, species which naturally colonise mine tailings dumps, are ideal indicators for the types of species to examine further in re-vegetation projects.

Likewise, Kaphaizi (2015) revealed that, *Leucaena leucocephala, Celtis africana* and *Eucalyptus camaldulensis* species characterized natural ecological succession in a study conducted on a decommissioned tailings dump established in 1982 at Renco Mine. In addition, Kaphaizi (2015) observed that, these species reached levels of contributing to the generation of organic matter and thereby improving its structure and fertility. In addition, Brackley and Ziupfu (1995) indicated that, *Dodonaea viscosa* was among the species that thrived well on the dump at Renco Mine. However, the studies were based on ecological succession on the tailings dump but could not establish early growth performance of these species on an operational tailings dump. Of concern, a revegetation programme is in progress on an operational tailings dump established in 1998 at Renco Mine.

A few tolerant plant species, most often exotics, with lower growth rates and not acclimatized to local conditions, were once planted on the tailings dump since 2006 in an attempt to reclaim it. In addition, the traditional way of revegetation of mine tailings dumps at Renco Mine was through application of natural soil on mine tailings dumps as remedy to address soil fertility challenges. In relation to that, Wijesekara et al., (2016) highlighted that, biosolids-associated mine site rehabilitation is an important strategy and has a significant role according to the perspective of environmental remediation. In view of this, Renco mine operates a sewer treatment plant which generates considerable volume of sewage sludge which can be probably used in the revegetation program at the tailings dump. The researcher noted that, inside a nursery established at the dump there were only two species nursed for the tree planting season namely, *Dodonaea viscosa* and *Leucaena leucocephala*. It is against this background that, the researcher proposed to undertake a study on early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* planted on different soil types applied on an operational mine tailings dump at Renco Mine.

1.2 STATEMENT OF THE PROBLEM

Tailings dumps cause environmental problems if they are not stabilized by vegetation. Heavy rains can easily wash the unstable dumps into streams, rivers and lakes resulting in social, economic and environmental damage. Moreover, a mine tailings dump destroys wildlife habitat, leach out toxic minerals into streams and groundwater and leads to several environmental impacts such as dust, erosion and acid mine drainage, that is, if not properly rehabilitated. In relation to this, Mulizane et al. (2005) revealed that the preferred strategy on mine tailings dumps rehabilitation is to initiate the normal ecological succession using low-cost techniques such as revegetation. Similarly, Baker and Brooks (1989) stated that, revegetation by plants can only be considered the first step in building up a self-sustaining ecosystem, and colonization by birds, insects and fungi is necessary before the system can be considered viable. Albeit, Troung (1999) indicated that, tailings materials consist mainly of crushed rock, with poor physical structure, less moisture content, metal toxicity, acid generating on the surface, high salt concentrations and lack essential nutrients for plant growth. That is, the composition of tailings makes re-vegetation of a tailings dump difficult. Since commissioning of the active tailings dump at Renco Mine in 1998, a few tolerant plant species, most often exotics, with lower growth rates and not acclimatized to local conditions, were once planted on the tailings dump in an attempt to reclaim it. However, little was done to study use of certain plant species on mine tailings rehabilitation since commencement of the revegetation program. In addition, application of the natural soil on mine tailings dumps as remedy to address soil fertility challenges was without scientific study, and biosolids generated at the sewage treatment plant have not been examined on the possible use in the revegetation program at the tailings dump. Kaphaizi (2015) indicated that, *Leucaena leucocephala* characterized natural ecological succession at Old Tailings dump at Renco Mine. More so, *Dodonaea viscosa* characterizes the surrounding tree vegetation adjacent to the tailings dump. However, these species have not been given due consideration to study early growth performance of species on mine tailings dumps at the mine. In view of this, the researcher conducted a comparative study on early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* planted on different soil types applied on an operational mine tailings dump at Renco Mine.

1.3 OBJECTIVES

1.3.1 General Objective

To compare early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* planted on different soil types applied on an operational mine tailings dump at Renco Mine.

1.3.2 Specific Objectives

- To measure height and root collar diameter during early growth of the species.
- To assess the survival rates of the species during early growth.
- To compare early growth performance of the species on different soil cover.
- To compare early growth performance of the species on different soil treatments.

1.4 HYPOTHESES

1. **H_0:** There is no difference in early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* on mine tailings dump **($\mu_1 = \mu_2$)**.

   H_1: There is difference in early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* on mine tailings dump **($\mu_1 \neq \mu_2$)**.

2. **H_0:** There is no difference in early growth performance of *species* on different soil treatments applied on mine tailings dump **($\mu_1 = \mu_2$)**.

   H_1: There is difference in early growth performance of *species* on different soil treatments applied on mine tailings dump **($\mu_1 \neq \mu_2$).**

3. **H_0:** There is no difference in early growth performance of *species* on grass covered soil and bare soil on mine tailings dump **($\mu_1 = \mu_2$)**.

   H_1: There is difference in early growth performance of *species* on grass covered soil and bare soil on mine tailings dump **($\mu_1 \neq \mu_2$)**.

1.4 SIGNIFICANCE OF THE STUDY

Firstly, the research offers an interactive platform to transfer knowledge from research to companies and other organisations that apply it. Zellner (2003) stated that, the benefits of developing human capital go well beyond formal education. Zellner (2003) added that, those who perform research acquire substantial tacit knowledge of how to make innovation work in

reality, and this knowledge is mostly transferred through direct contact or mobility of people. In view of this, being employed at Renco Mine as a Safety, Heath and Environmental Management Officer, the researcher seemly shall add knowledge on species to use in rehabilitation of the operational tailings dump at Renco Mine. In this case, the interface in-between environmental problems at mine tailings dumps and knowledge obtained by the researcher becomes more practical in suggesting solutions and/or making recommendations making the research worthwhile.

The research is in line with actions that comply with legal requirements on environmental management in relation to management of mining waste as committed by the mine's Safety, Heath and Environmental Management (SHE) policy. Section 73(1)(b)(i) of the Constitution of Zimbabwe (Amendment No. 20) Act (2013) as read with the Environmental Management Act (Chapter 20:27) on Section 140(2)(c) as well as Section 24(1)(b) of S.I. 6 of 2007 prescribes proper management of mining waste such as tailings materials. Mulizane et al. (2005) suggested that, the preferred strategy on mine tailings dumps rehabilitation is to initiate the normal ecological success using less-cost techniques such as revegetation. However, Stanley et al. (2000) pointed out that, tailings materials are inappropriate for plant growth, as a result there is need to assess the performance of different species in re-vegetating tailings dams. Hence, this research work became meaningful to provide a suggestive and indicative insight in the selection species for the revegetation of the active tailings dumps. In other words, the research shall reflect on opportunities to explore further on plant species in relation to rehabilitating tailings dumps. Ultimately, compliance with environmental management statutes shall be upheld when rehabilitation work progresses well.

The research augments knowledge base of the researcher in the area of re-vegetation of mine tailings dumps as well as other researchers in this subject. In line with this, Georghion (2015) stated that, knowledge created by one researcher can be used by another without finacial compansation. That is, a positive extenality comes in form of knowledge spillover. In relation to this, the academic field at large shall benefit from a new applied inquest which shall be published at the University library, and further contribute to the existing literature resource base for learning purpose.

The research probably builds a model in bringing the deserted land back into valuable use and appreciable contribution to the environment. Sheoran and Poonia (2010) stated that, once the abandoned mine lands have vegetation growing on the surface, the regeneration of these areas for productive use will begin and offsite damages will be minimized. That is, vegetation rehabilitation supports the minimization of wind and water erosion from the tailings dumps, improves aesthetics, no production of waste products, increase soil organic concetrations, binds metals, hence the land and surrounding ecosystems can be productive. In addition, vegetation, particularly trees, probably would reduce net percolation through the soil or mine spoil material and reduce the leaching potential of the metals.

More to that, the research upholds a commitment prescribed in the mine's SHE policy in relation to minimizing pollution. The policy states that, environmental pollution and disturbances arising from processes, products and services are prevented or minimised wherever possible. Thus, vegetative rehabilitation supports the minimization of wind and water erosion from the tailings dumps. Prospectively, the research is determined to uphold the essence of continual improvement with regards to rehabilitation of tailings dumps at Renco Mine. Based on all the above mentioned, there is overwhelming evidence from multiple sources to justify the research.

1.5 STUDY AREA

1.5.1 Study Site

Renco Mine is a large scale gold mine located in Nyanjena Communal Lands under Masvingo Rural District south of Masvingo province. The mine is 5Km north of Bangala Dam along Mutirikwi River and 75 km south of Masvingo City, that is, 20° 37' 33" South and 31° 9' 59" East as shown in Figure 1.1. The research was carried out at an operational tailings dump, which was established in 1998 at Renco Mine. The southern side of the dump was targeted for the study with a total area of 1.56ha and a rising slope of 22°.

1.5.3 Climate

Brakely and Ziupfu (1995) indicated that, Renco Mine falls under Natural Region V in the Lowveld area of Zimbabwe, and the area experience summer temperature in the range of 30^oC to 40^oC with an average annual rainfall of less than 500mm. Nhandara et al. (1997) also indicated that, the Lowveld region is hot and dry with mean annual rainfall of less than 500mm, and the

rainfall is very unreliable and drought is common. Gambiza and Nyama (2000) noted that, the region is usually so dry for successful crop production especially without irrigation.
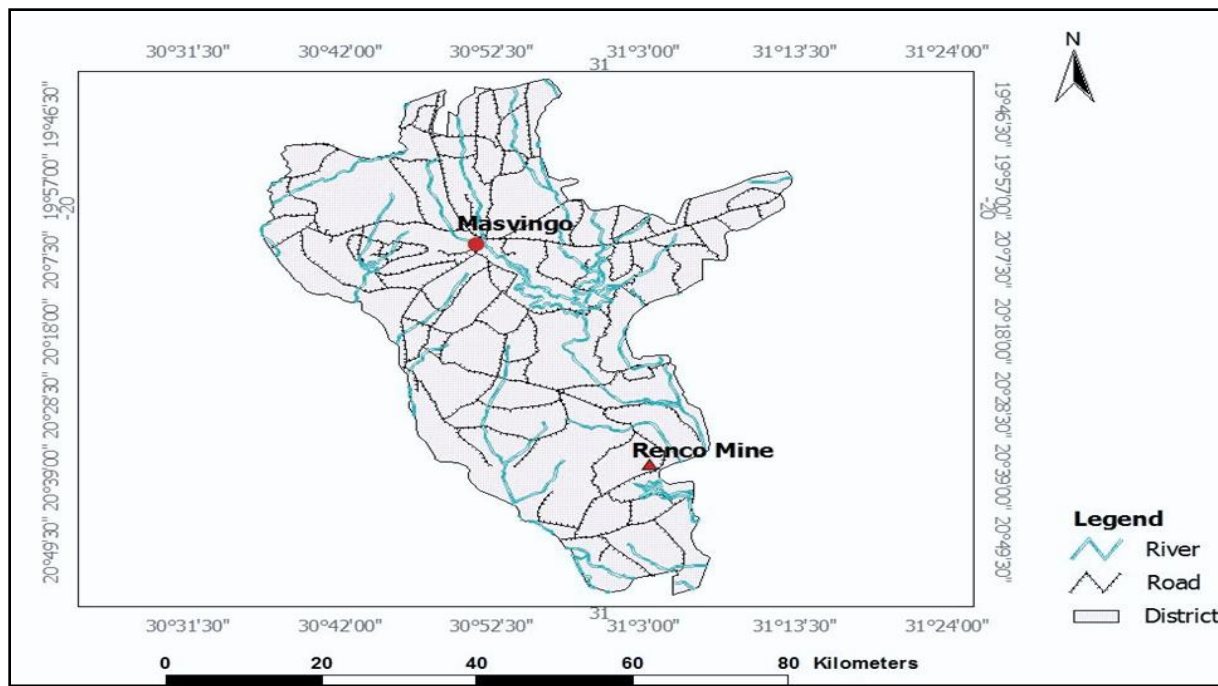
Figure 1.1: Locality of Renco Mine in Masvingo District

1.5.2 Human Geography

Nyajena Communal Land is a communal area with villagers sparsely settled. Villages of Muvango, Mupondi, Makonesi, Mashapa, Maramba, Muzondo, and Chikwenhere surrounds the mine. Agriculture is the main livelihood for many rural community of Nyajena. The communal area is characterized by mixed farming activities such as crop farming, livestock production, poultry, and apiary. The crops that are commonly grown in fields include maize, groundnuts, round-nuts, sweet potatoes, rapoko and finger millet with maize being the primary staple grain. However, some cash crops are also grown at Rupike Irrigation. For instance, beans, wheat, onions, cabbages and carrots. In addition, a number of community gardens were established in partner with non-governmental organizations (NGOs) as a result market gardening is also part of agricultural activities in the communal land. However, crop production in the communal area is mainly rain fed. Rupike Irrigation Scheme is the major irrigation scheme supporting livelihoods in the communal land located approximately 5Km from Renco Mine. On livestock, most villagers keep cattle as a form of wealth and for drought power whilst goats, sheep and poultry are usually for supplementary feeding. Renco Mine has a compound settlement with 1010 houses accommodating most of the employees, and also recreational facilities such as clubs, sporting

fields and halls. According to RIZIM (2016), the mine had a complement of 1150 employees in year 2016. Thus, the mine is the main source of livelihood for the employees, and also forms a market for selling crop and livestock produce from surrounding villagers.

1.5.4 Vegetation

Renco Mine area is dominated by woody vegetation essentially confined to the hillsides, which are still partly covered with Miombo Woodland. The dominant tree species on all hills are *Brachystegia spiciformis and Brachystegia glaucescens.* Most of the flat land has had its timber removed and consist of fields, gardens, the mine compound and the tailings dump. The remainder is grassland with widely scattered trees and some denser woody vegetation where there are rock outcrops. Patches of riparian woodland occur along the Mutirikwi River and some of its tributaries. Other common trees are *Albizia versicoloi* (mainly on slopes), *Julbernardia globiflora, Dalberbiella nysa, Kirkia acuminate, Combretum molle, Diplofhynchus condylocarpon, Diospyros mespiliformis, Olax dissitiflora, Pseudolachnostylis maprouneifolia, Ficus glumosa, Sclerocarya birrea* and *Strychnos madagascariensis.* A most interesting feature in the Borassus palms which are extremely rare in Zimbabwe, only known from the lower Rusitu Valley near the Mozambique border and Renco Mine and its surroundings (Brakely and Ziupfu, 1995).

1.5.5 Geology and Soils

More than 70% of the area at Renco Mine is underlined by granulites which forms an area of hills aligned north-east. The soils of the enderbite hills mainly cover the area. The soils are dark-reddish brown loamy sand of colluvial origin over residual pockets of red sandy clay loam to sandy clay. Their depths results in part from interactions between the soil's inherent fertility and the stabilizing vegetation, mainly well grown *Brachystegia spiciformis* woodland. Soil associated with less grown *Brachystegia spiciformis* woodland on siliceous gnesiss hill slopes are mainly dark brown, fersiallitic, medium grained and light textured. The valleys of both the enderbite and siliceous gneiss contain alluvial/colluvial deposition with medium grained and loamy sands on upper slopes giving way to similar loamy sands over hydromorphic sandy clays further down slope. The somewhat hydromorphy of the area results from the large quantities of run-off and groundwater received from the surrounding hills. Land Suitability Classification is VI-VII with land use most suitable for wildlife, limited to moderate grazing (Brakely and Ziupfu, 1995).

CHAPTER 2: LITERATURE REVIEW

2.1 MINE TAILINGS DUMPS AND ENVIRONMENTAL IMPACTS

Guoqing et al. (2017) indicated that, mining activities can generally give rise to vegetation deterioration, soil erosion, geological hazards and environmental pollution, which restrict the sustainable development of mining areas. It is important to note that, the quantity of an extracted ore body commonly causes environmental impacts after mineral processing. Cook and Johnson (2001) pointed out that, mining activities includes primary extraction, milling, and processing, refining and waste disposal in the form of rock and tailings dumps. In relation to that, Dumba (2013) mentioned that waste generation and disposal of waste is the drive of most of the extensive destruction and pollution on land. On that remark, Kossoff (2014) mentioned that, the chief waste stream in mining is tailings, which are often stored in impoundments behind dams with ensuing environmental, health and economic impacts. Lottermoser (2007), defined tailings as mixtures of crushed rock and processing fluids from mills, washeries or concentrations that remain after extraction of economic metals, minerals, mineral fuels or coal from the mine resource. MAC (1998) stated that, tailings facilities provide a window on the mining industry, thus, they tell a story to the public about how the industry manages its activities. MAC (1998) added that, tailings pose a risk that must be managed in the long term. Likewise, Renco mine tailings dump facilities are not an exception to environmental impacts hence the need to embark on rehabilitation programs such as revegetation.

According to Cook and Johnson (2001), if a mining project involves the extraction of a few hundred million metric tonnes of mineral ore, then the mine project will generate a similar quantity of tailings. For instance, RIOZIM (2016) revealed that, ore hoisted in year 2016 was 276028t against a total of 260092.2t of tailings disposal translating to 94% of ore extracted during the year. In line with that, Bell (1998) indicated that mine waste represent the highest proportion of waste produced by industrial activity, with billions of tonnes being produced annually. That is, the beneficiation process generates high volume waste called tailings, the residue of an ore that remains after it has been milled and the desired metals have been extracted, in this case gold. In line with that, Wright et al. (2004) mentioned that, the exposed mine tailings contribute to erosion and sedimentation due to absence of vegetation cover. Miller (1992) noted that, the waste disposal through dumping on mine tailings creates serious environmental and health problems to communities that live close to the abandoned mines and mine tailings. In

relation to that, Brnich and Mallet (2003) stated that, these mine tailings are rich in heavy metals and potential source for acid mine drainage. In this regard, Guoqing et al. (2017) mentioned that, mining areas are thus a typical vulnerable ecosystem.

In addition, Kossoff et al. (2014) indicate that, the structural nature of the impoundment and the direct results of overflows, and wall failures may affect the surrounding environment. Such impacts include long-term seepage that results in groundwater contamination, disturbance of wildlife habitat and dust emission. Kossoff et al. (2014) added that, the structural failures generally results in rapid release of material over a short time span. In the same line, Mulizane et al. (2005) stated that mining tailings dumps leach out toxic minerals into streams and groundwater with toxic minerals thereby destroying wildlife habitats. In agreement with that, Edwards (1996) indicated that, the sheer magnitude and often toxic nature of the material held within tailings dumps means that their erosion, and the ensuing discharge into river systems, will invariably affect water and sediment quality, and aquatic and human life for potentially hundreds of kilometers downstream.

Kossoff et al. (2014) mentioned that, how a mining company disposes of this high volume toxic waste material is one of the central questions that will determine whether the mining project is environmentally friendly. The key long term goal of tailings disposal and management is to prevent the mobilization and release into the environment of the tailings. In this regard, it is important to rehabilitate affected ecosystems within mining surrounding, for instance revegetation of mine tailings dumps.

2.2 ENVIRONMENTAL MANAGEMENT LAWS ON MINE TAILINGS DUMPS

UN (1992) reported on Agenda 21 premised on the need to take a balance and integral approach to environment and development questions. Agenda 21 addresses the pressing problems of today and also aims at preparing the world for the challenges of the next century. In relation to revegetation of tailings dumps, UN (1992) stated that, one of the management related activities to combat desertification is to carrying out revegetation in appropriate mountain areas, highlands, bare lands, degraded farm lands, arid and semi-arid lands and coastal areas. It is also against the background of Agenda 21 principles as stated in Section 8 paragraphs 8.13, 8.14 and 8.15 that, the Government of Zimbabwe through S.I. 103 of 2003 gazetted the Environmental Management Act (Chapter 20:27) in 2003 on the 17th of March.

The Environmental Management Act (Chapter 20:27), provides for environmental rights as prescribed in Section 4 (1) stating that, every person shall have a right to a clean environment that is not harmful to health; and access to environmental information, and protect the environment for the benefit of present and future generations. These rights were later on enshrined in the Constitution of Zimbabwe (Amendment No. 20) Act (2013). Section 73 reads, (1) every person shall have a right to (a) environment that is not harmful to their health or wellbeing; and (b) to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that (i) prevent pollution and environmental degradation; and (ii) secure ecologically sustainable management and use of natural resources while promoting justifiable economic and social development. Section 140 (2) (c) of the Act as read with Section 24 (1) (b) of S.I. 6 of 2007 prescribes rehabilitation and management of mining waste. Additionally, Section 4 (2) (e) of the Environmental Management Act (Chapter 20:27) stipulated that, development must be socially, environmentally and economically sustainable. Section 4 (2) (f) prescribed that, anticipated negative impact on the environment and on people's environmental rights shall be prevented, and where they cannot be altogether prevented, be minimized.

Furthermore, Section 25 of S.I. 109 of 1990 stipulates that, every dam and dump which has been approved in terms of Section 225 of the Mines and Minerals Act (Chapter 21:05) and is to be built for the purpose of impounding tailings, slimes, sand or water shall be constructed under the supervision of a competent person in such a manner as not to endanger life or limb or cause damage to property. In addition to that, Section 26 (1) prescribes that, tailings dumps shall be properly designed and constructed and adequately maintained. In view of that, this research study complements effort to comply with legal requirements on environmental management in relation to rehabilitation of mining waste as committed by the mine's Safety, Heath and Environmental Management (SHE) policy.

2.3 MINE CLOSURE PLANS ON TAILINGS DUMPS

MMCZ (2015) highlighted that, in Zimbabwe the mining sector continues to be one of the major foreign currency earner, and the sector was infused in Cluster 4 on Value Addition and Beneficiation of Zimbabwe Agenda for Sustainable Socio-economic Transformation (ZIM-ASSET) to show its importance to the economy of the country. In line with that, Ashton et al. (2001) stated that despite adverse economic feature and depressed commodity prices for minerals

and mineral products, mining and its associated industries continue to form the cornerstone for the economies of most southern African countries. However, Baker and Berthelot (1999) indicated that, the mining industry is faced with the fact that ore bodies have a finite life. In most cases, tailings dumps are an open feature left without proper management. As a result, Johnson et al. (1994) indicated that, continuing environmental damage from wind-blown dusts and dispersal of contaminated solid waste is a feature of mines throughout the world. In relation to that, Sheoran and Poonia (2010) stated that, once the abandoned mine lands have vegetation growing on the surface, the regeneration of these areas for productive use will begin and offsite damages will be minimized..

However, in relation to tailings dumps closure plans, reclamation of the tailings dumps at decommissioning stage can be difficult. Gardner (2001) noted that, in too many instances mine dumps have been abandoned with limited or rehabilitation treatment. For instance, Nyakudya et al. (2011) revealed that, tailings dump at Rein Gold Mine in Bindura was left bare without any rehabilitation. As a result, Ashton et al. (2001) indicated that many mine-related environmental impacts often continue long after the mine has stopped production and has been closed. For instance, Baker and Berthelot (1999) indicated that, amongst the more pronounced post-closure impacts on record is landscape scarring in the form of un-rehabilitated mine tailings dumps, waste rock dumps and discarded dumps. According to Schoenbrunn and Laros (1997), one of the main concerns with tailings dumps is the long-term geotechnical stability of the water retaining structures. Often these tailings retain high levels of metals or other compounds and are generally devoid of the organic constituents that are required for vegetation colonization (Baker and Berthelot, 1999). A serious question now facing the mining industry and government is how these facilities can be best be safely managed to ensure protection of human and the environment in the long term (Baker and Berthelot, 1999). Therefore, there is need to develop mine closure plans including revegetation of mine tailings dumps. In light to that, a scientific enquiry on successful implementation of revegetation programs may be required thus an opportunity for research work to serve as a knowledge base in that regard.

2.4 REVEGETATION OF MINE TAILINGS DUMPS

Guoqing et al. (2017) indicated that, in recent years, revegetation around mines has attracted the scientific community's attention. In view of that, Guoqing et al. (2017) pointed out that, to recover and maintain sustainable ecosystem around mines, revegetation has become one of the

main means of ecological restoration of mining areas. Reclamation of mining areas largely improved vegetation cover (Guoqing et al., 2016). In a study to compare growth performance of exotic species *Eucalyptus grandis* and *Acacia saligna,* and indigenous species *Acacia polyacantha* and *Bauhinia thonningii* in rehabilitating active gold mine tailings dump at Shamva Mine in Zimbabwe, Mulizane et al. (2005) concluded that, indigenous species compare favorably with exotic tree species in both survival rates and growth performance and can be used in gold mine tailings dump rehabilitation. Mulizane et al. (2005) revealed that, mean height increment of exotics significantly surpassed indigenous tree species. Mulizane et al. (2005) indicated that, *E. grandis* performed best followed by *A. saligna,* and *A. polyacantha* was highest on root collar diameter followed by the exotics but *B. thonningii* showed the lowest height increment. There was no significant difference for the mean root collar diameter and height between the exotics and indigenous species (Mulizane et al., 2005).

In another case study, revegetation of Sullivan Mine was initiated in 1972, Gardiner (1974) indicated that, initial attempts to establish trees and shrubs focused on modifying mine and mill waste with variety of amendments including lime and fertilizer. Gardiner (1974) revealed that, seedling survival was highly variable and plantings were not successful. According to Przeczek (2004), through the mid 70's and 80's woody species were often planted at the time of seeding with various grass and legume seed mixes. However, Przeczek (2004) revealed that, survival was generally poor and there was limited opportunity to determine which tree and shrub species had the greatest potential for use in the reclamation program. Similarly, Gruffit and Toy (2001) established that, both native and introduced species performed well after revegetation programme on iron ore mines in Minais Gerais state in Brazil. Graffit and Toy (2001) noted that, tree and shrub species were set out with the use of fast growing native species (*Sema machantera, Tibouchina granulose,* and *Vismia species*) and introduced species (*Acacia mangium, Lueceana species*). Additionally, Mukhopadhyay and Masto (2016) indicated that, revegetation around mining areas causes a linear increase in soil organic carbon stock with time. In addition, revegetation around mining areas has also been proposed as a suitable technique to reduce metal toxicity and improve soil fertility (Touceda-Gonzalez et al., 2017). In consistent with sustainable development principles, tailings dumps should be intended as a transient land use. This means that after dumping, the condition of the land should be restored so that its value is similar to or greater than it was before dumping (Gardner, 2001). Tailings rehabilitation should be the process of converting tailings dumps to their valuable use and not a process of burying

waste, smoothing out the landscape and applying a green mantle of relatively valueless vegetation (Mulizane et al., 2005) Relatively, a number of benefits are realized from revegetation of mine tailings dump including erosion control, restoration of degraded ecosystem, immobilization of tailings materials and toxic elements, reduced siltation and pollution of water bodies from tailings material. Therefore, based on the literature above, the researcher attempts to complement the idea to rehabilitate mine tailings dumps by means of revegetation with the concept of comparing growth performance with intention to improve the performance of the whole program.

2.5 SOIL FERTILITY CHALLENGES ON PLANT GROWTH

Mulizane et al. (2005) noted that, revegetation of tailings dump is made difficult due to the fact that the sites are composed of freshly crushed rock with metal toxicity, high salt concentration, poor physical structure, less moisture content and lack essential nutrients for plant growth. In agreement to this, Juwarkar et al. (2009), mine reclamation poses a great number of challenges given the often huge scale of the disturbance, that mine dumps typically have low organic content and water holding capacity, are frequently nutritionally deprived, and have a lack of nutrient cycling due to a lack of vegetation, mycorrhizal fungi and other microbial action. Furthermore, Singh and Jha (1993) stated that, nitrogen (N) and phosphorus (P) are the two major limiting nutrients in mine tailings thwarting the establishment and growth of plant species

As a result of poor soil characteristics such as low-level organic matter and poor soil texture and structure, these shortfalls and overburdens are identified as drastically unproductive land masses (Wijesekara et al., 2016). Ultimately, infertile soils and harsh conditions associated with these disturbed lands can adversely affect the establishment of soil microbial life, earthworms, other soil fauna and plant growth (Wijesekara et al., 2016). Therefore, disturbed lands such as tailings dump needs to be rehabilitated to avoid potential environmental consequences and to restore the lost ecological life.

2.6 SOIL REMEDIATION ON MINE TAILINGS DUMPS

Stanley et al. (2000) indicated that, soil has significant role in the restoration process due to the fact that tailings are totally inappropriate for vegetation growth. Therefore, there is need to create proper conditions for plant growth. EPA (2006) defined a soil amendment as a material that is applied to a substrate in an effort to improve the essential conditions required for adequate plant

growth, and/or for reducing the mobility and bioavailability of any soil contaminants. Amendments are often used in the reclamation of soils and unconsolidated over burden, which in almost all cases, lack optimal conditions for plant growth (EPA, 2006). These substrates can generally be described as having potentially low levels of plant available nutrients such as N and P, high concentration of heavy metals, low organic matter content, high salt content and lower or higher than normal pH (EPA, 2006).

In relation to that, Milczarek (2006) noted that, a number of studies have shown that the additional organic matter to tailings materials such as biosolids and green waste improves the textual properties and fertility and promotes re-vegetation. In the same line, Forge et al. (2006) indicated that, the abundance and diversity of soil organisms are considered to be prime indicators of soil health, which is defined as the capacity of soil to sustain productivity. According to Sekhar and Jakhu (2005), in an attempt to vegetate tailings dumps it has been noted that while milky latex containing plant can be grown without any preconditioning of the soil, almost any plant can be grown after proper conditioning. Norman and Raforth (1998) stated that, plant growth on mine tailings dumps can be aided by the availability of topsoil and additions of biosolids, hay, paper residue and compost. Norman and Raforth (1998) added that, if soil recently stripped from a nearby area is used as a cover on the tailings dump, it will likely contain native seeds needed to aid rapid revegetation.

According to Forge et al. (2006), municipal biosolids are good sources of N, P, and micronutrients for short term crop production. Biosolids can be defined as stabilized organic solids derived from sewage treatment processes which can be managed safely to be used beneficially for their nutrient, soil conditioning, energy, or other values (Wijesekara et al., 2016). Forge et al. (2006) added that, biosolids have potential to increase soil biodiversity and improve soil health. However, because they contain greater concentrations of some metals than receiving soil, there is potential for biosolids to have regressive effects on soil biodiversity and soil health. Municipal biosolids are used extensively for mine and landfill reclamation and better knowledge of how biosolids influence the health of agricultural soils should improve understanding of the long-term benefits and constraints of using biosolids in mine and landfill reclamation (Forge et al., 2006)

For instance, Horton and Kempe (2001) revealed that, in 2001 DL 1796 Tailings (Phase One reclamation with biosolids in 1996) and DL 2900 Old Tailings (Phase Two reclamation with biosolids in 1997) at the Hedley Gold Tailings Project have shown continued forage production for five and four growing seasons respectively without further treatment or chemical fertilization. This forage establishment has resulted in decreased tailings dust and improved aesthetics for the Hadley community. No adverse effects to the surface or ground water, soil or vegetation have been observed in the monitoring data form the application of biosolids (Horton and Kempe, 2001).

According to Wijesekara et al. (2016), modern wastewater and sewage treatment facilities generate biosolids in large quantities. Globally, around 10×10^7 tons per year of biosolids generated (Wijesekara et al., 2016). In 2050, the world's population is projected to be 9.6 billion and will potentially generate 17.5×10^7 tons per year of biosolids at a rate of 50g per person per day (Wijesekara et al., 2016). Furthermore, Wijesekara et al. (2016) indicated that, 66% of the world's population (7.4 billion) is forecasted to be urban by 2050. This urban population will generate 13.5×10^7 tons per year of biosolids. To manage this large quantity, the most appropriate strategy woud be reuse and recycling. Biosolids are reused in different ways such as a fertlizer or soil conditioner. For instance, Wijesekara et al. (2016) indicated that 6% and 4% are used in landscaping (composting) and land rehabilitation respectively. Among sustainable uses, biosolids-associated mine site rehabilitation is an important strategy and has a significant role according to the perspective of environmental remediation (Wijesekara et al., 2016).

Furthermore, according to Wijesekara et al. (2016), the addition of biosolids enhances most soil physical properties in degraded lands from mining. The high organic matter of biosolids is the main cause for improvement in physical properties in mine spoil soils. Improvements in physical properties including decreased bulk density and temperature, increased porosity and aggregation, increased hydraulic conductivity and water holding capacity, increased infiltration, maintained soil texture, and reduced erosion and sedimentation have been reported in mine spoil rehabilitation with biosolids (Wijesekara et al., 2016). The application of biosolids causes a reduction in bulk density in degraded soils by increasing pore space by enhancing macro-pores, meso-pores, and micro-pores, thereby increasing the field capacity (Wijesekara et al., 2016). In relation to this, Zanuzzi et al. (2009) reported that a remarkable increase in porosity and aggregate stability has been reported in acidic tailings rehabilitation with sewage sludge in Spain.

Furthermore, Wijesekara et al. (2016), the application of biosolids raises chemical properties such as pH, EC, CEC, nutrient contents, and organic matter in soils. The presence of clay, mineral particles, and organic colloids in biosolids increases the CEC in the receiving degraded sites (Gardner et al., 2010). The application of biosolids to mine spoils increases key plant nutrients such as N, P, Ca, and S, thereby increasing fertility and accelerate mine site rehabilitation (Larney and Angers, 2012). Biosolids application increases microbial biomass carbon and microbial enzymatic activities in receiving mine spoils (Gardner et al., 2010). Biosolids creates an energy-rich soil environment favorable to soil microorganisms by increasing soil organic matter, which is the main energy source of microbes (Wijesekara et al., 2016). For instance, Gardner et al. (2010) stated that, an increased amount of soil microorganisms such as denitrifiers, sulfate reducers, total aerobic microorganisms, and total anaerobic heterotrophs was observed in a mine site rehabilitated with biosolids in Canada. However, Waterhouse et al. (2014) indicated that the mortality of earthworms increased owing to biosolids application in a mine site rehabilitation in New Zealand, which further suggest the need for ecological test before implementing strategies. In light to that, there is knowledge gap in the usage of top soil applied on tailings materials which have very poor in soil fertility. Therefore, there is need to incorporate study on different types of top soils used in revegetation of mine tailings dumps.

2.7 GROUND COVER EFFECTS ON PLANT GROWTH

According to Rizza et al. (2007), species react differently to planting stress, competition for light, water and nutrients, and even browsing and erosion. Rizza et al. (2007) added that, grasses have been shown to compete with trees for water and nutrients in a number of ecosystems. Ashby and Kost (1989) supported the use of warm-season grasses for revegetation of mined sites, but warned that their size and competitive ability may limit tree growth. In a case study, Franklin and Buckley (2006) noted that, although the growth of northern red oak and sugar maple was high in the absence of cover, there was no apparent growth response to increasing amounts of cover. Rizza et al. (2007) added that, they also showed the greatest growth in the native warm season grass treatments.

Additionally, Franklin and Buckley (2006) noted that, Eastern redbud and Virginia pine typically grow best in environments with high light and low competition. Franklin and Buckley (2006) further revealed that, while redbud survival was highest at intermediate cover classes, survival of Virginia pine decreased with increasing cover. In relation to that, Rizza et al. (2007) pointed out

that, the root collar diameter growth of both species decreased with increasing ground cover, suggesting that diameter growth of both species is relatively intolerant of competition. Franklin and Buckley (2006) indicated that, both species had some foliage near ground level, where light levels were reduced by ground cover. Competition for water and nutrients could have potentially reduced seedling growth rates (Rizza et al., 2007). Northern red oak and sugar maple had greater survival rates, and similar responses to ground cover, and the main influence on the survival of these seedlings was winter mortality (Rizza et al., 2007). Franklin and Buckley (2006) pointed out that, both species had greater survival rates when surrounded by moderate amounts of groundcover, and higher transpiration rates in the second year when surrounded by higher amounts of groundcover. This suggests improved water relations at moderate amounts of groundcover (Franklin and Buckley, 2006). In view of these cases, it is important to note that, early growth performance of species planted on different ground cover might give different result hence there is need to assess performance of species with regards to ground cover.

In relation to the later, Ranjan et al. (2015) indicated that, grasses are considered as a nurse crop for an early vegetation purpose. However, Ranjan et al. (2015) indicated that, grasses have both positive and negative effects on mine lands. Ranjan et al. (2015) added that, they are frequent needed to stabilize soils but they may compete with woody regeneration. Grasses can offer superior tolerant to drought, low soil nutrients and other climatic stresses (Shu et al., 2002). Ranjan et al. (2015) stated that, roots of grasses are fibrous that can slow erosion, and their soil forming tendencies eventually produce a layer of organic soil, stabilize soil, conserve soil moisture and may compete with weedy species. According to Shu et al. (2002), the initial cover from grasses must allow the development of diverse self-sustaining plant communities.

2.8 PLANT SELECTION ON REVEGETATION OF TAILINGS DUMPS

According to Grange (1973), selection of plants determines the establishment of plant species that will grow on the tailings dump. Milizane et al. (2005) stressed that, although the idea of using indigenous species in vegetation of tailings dumps is now widely accepted there is need for continued investigation into the establishment of indigenous species which perform comparably to exotic species on tailings dumps. Corps (1990) indicated that, serious there are no 'miracle trees' which always do well on all sites, yet there are generally trees which are well adapted to all but the most extreme sites. This implies that, serious consideration must be given to match the environmental requirements of the desired species to the planting environment. Therefore, proper

establishment of vegetation cover depends mainly on the selection of plant species that will grow, spread and thrive under hostile conditions provided by the nature of the dump material.

In relation to that, Swann (2007) pointed out that selection of suitable plants is site specific and influenced by the local climate, and species which naturally colonise mine sites are ideal for the types of species to examine for further in revegetation projects. Swann (2007) added that, native or locally acclimatized plants are commonly chosen for long-term revegetation in order to establish an ecological situation similar to that prevailing before the mine was developed. Likewise, Kaphaizi (2015) noted that, *Leucaena leucocephala, Celtis africana* and *Eucalyptus camaldulensis* species characterized natural ecological succession in a study conducted on a decommissioned tailings dump established in 1982 at Renco Mine. In view of the above, the researcher went on to study *Leucaena leucocephala* and *Dodonaea viscosa* which is another species local to the surrounding areas of Renco Mine tailings dumps.

The establaishment of native species in reclaimed areas is a goal of many reclamation plans, but research on reclamation vegetation at Coal Valley Mine indicates that although richness and native cover do increase with time, native species remain a small component of the vegetation communities (Strong, 1998). In line with that, Swann (2007) suggested that, species which naturally colonise mine tailings dumps are ideal indicators for the types of species to examine further in re-vegetation projects. However, Williams and Crone (2006) stated that generally the use of the agronomic species while efficient for short term goals on ground cover and erosion control, probably interferes with the establishment of native species. In light to this, *Leucaena leucocephala* is an agronomic species while *Dodonaea viscosa* is an indigenous native species found at Renco Mine tailings dump which can be investigated on early growth performance in rehabilitation of the dump.

According to Yang et al. (2003), on mine spoils, nitrogen is a major limiting nutrient, and regular addition of fertilizer nitrogen may be required to maintain healthy growth and persistence of vegetation. In this regard, Singh et al. (2004) indicated that an alternative approach might be to introduce legumes and other nitrogen-fixing species. Ranjan et al. (2015) revealed that, nitrogen-fixing species have a dramatic effect on soil fertility through production of readily decomposable nutrient-rich litter and turnover of fine roots and nodules. Zhang et al., (2001) added that, mineralization of N-rich litter from these species allows substantial transfer of companion

species and subsequent cycling thus enabling the development of a self-sustaining ecosystem. In line with this, Orwa et al. (2009) indicated that, *Leucaena leucocephala* has high nitrogen-fixing potential (100-300Kg N/ha per year) related to its abundant root nodulation, and thrives on steep slopes and in marginal areas with extended dry seasons, making it a prime candidate for restoring forest cover. Therefore, the researcher subjected *Leucaena leucocephala* in this study as one of the species to rehabilitation tailings dump at Renco mine.

Furthermore, Singh (2015) indicated that, *Leucaena leucocephala* performs well on mine tailings although in early growth performance of the tree is poor. According to Soni (2009), *Dodonaea viscosa* has higher soil binding capacity and can be used for fast stabilization of degraded ecosystems. In agreement with that, Pearman (2002) stated that, *Dodonaea viscosa* is used in reforestation, reclamation of marshes and degraded land, and as a soil stabilizer. Rani et al. (2009) indicated that, *Dodonaea viscosa* tolerates sandy or rocky soils, salt spray, windy areas and drought conditions, and it favors areas that receive full sun and is often cultivated in loamy or sandy soils. ICREF (2011) revealed that, areas which lack any nutrient containing soil can be planted with *Agave americana, A. sisalana, Dodonaea viscosa, Euphorbia tirucalli, E. tortilis, Mimosa hamata, Tecoma stans* and *Sterculia urens* which has been proved successful in extreme conditions. In view of this, there is an opportunity to investigate performance of both species at an early growth stage in rehabilitation of mine tailings dump.

2.9 SUSTAINABLE DEVELOPMENT GOALS AND MINING

Human and other animals rely on other forms of life on land for food, clean air, clean water, and as a means of combating climate change (UNDP, 2015). In addition, UNDP (2015) indicated that, plant life makes 30% of the human diet, and forests which cover 30% of the earth's surface, help to keep the air and water clean and the earth's climate balance as well as a home to millions of animal species. But the land and life on it are in trouble. Arable land is disappearing 30 to 35 times faster than it has historically (UNDP, 2015). Deserts are spreading and animal species are going extinct (UNDP, 2015). Fortunately, the SDGs aim to conserve and restore the use of terrestrial ecosystems such as forests, wetlands, drylands and mountains by 2020 (UNDP, 2015).

According to Ruppel and Ruppel-Schlichting (2011), the international community under United Nations Environmental Programme (UNEP) signed Rio Declaration 1992 on biodiversity and protection of the ecosystem where governments agree to general principles and an action plan on

ecosystem and biodiversity protection and sustainable use of natural resources for current and future generations. Thereafter, UNDP (2015) revealed that, after the successful implementation of Millennium Development Goals (MDGs), a new set of goals, the Sustainable Development Goals (SDGs), aims to end poverty and hunger by 2030. These goals were set after world leaders recognized the connection between people and planet. According to UNDP (2015), Goal 15 of the SDGs is basically on protection, restoration and promotion of sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. In light to that, the aspect of tailings dump revegetation promotes the opportunity to restore the ecosystem that was there before the dump was establishment thereby creating an opportunity for the present and future generations to benefit from the restored ecosystem services.

CHAPTER 3: RESEARCH MATERIALS AND METHODS

3.1 RESEARCH DESIGN

This section explores the subject of research design and methodology as well as to substantiate the choice made in the study. Research design is the blue print or framework for collection, measurement and analysis of data (Pandey et al., 2015). Bless et al. (2006) define research design as operations to be performed, in order to test a specific hypothesis under a given condition. Welman et al. (2005) viewed a research design, as the functional plan in which certain research methods and procedures are linked together to acquire a reliable and valid body of data for empirically grounded analysis, conclusion and theory formulation. This plan, at minimum, spells out the variables that will be studied, how they will be studied, and anticipated relationship to each other (Spector, 1981). In this regard, a research design is a set of logical procedures that enables one to obtain evidence to determine the degree to which a theoretical hypothesis or set of hypothesis is or are correct. Mouton (1996) states that, the main function of a research design is to enable the researcher to anticipate what the appropriate research decisions are likely to be, and minimize the validity of the eventual results. The research design thus provides the researcher with a clear research framework, and it guides the methods, decisions and sets the basis for interpretation. Therefore, a research design is applied so that suitable research methods are used to ensure the attainment of objectives for the research study.

According to Creswell (2003), there are three elements of inquiry central to the design of a research namely; knowledge claims, strategies of inquiry, and methods of data collection and analysis. Creswell (2003) added that, these approaches, in turn, are translated into processes in the design of research. Phillips and Burbules (2000) stated that, by stating a knowledge claim means that researchers start a project with certain assumptions about how they will learn and what they will learn during their inquiry. In line with this, Creswell (1994) mentioned that, philosophically, researchers make claims about what is knowledge (ontology), how we know it (epistemology), what values go into it (axiology), how we write about it (rhetoric), and the processes for studying it (methodology). To add on, Creswell (2003) indicated that, there are four schools of thought about knowledge claims namely; postpositivism, constructivism, advocacy/participartory, and pragmatism.

However, since this research on comparative study of early growth performance of species planted on a mine tailings dump is more experimental, the researcher employed postpositivism. Creswell (2003) revealed that, postpositivism assumptions have represented the traditional form of research, and these assumptions hold true more for quantitative research than qualitative research. In relation to this, Neuman (2000) stated that, if a problem calls for the identification of factors that influence outcome, the utility of an intervention, and understanding the best predictors of an outcome then a quantitative research design is the best. This position is sometimes called "scientific method" or doing science. It is also called quantitative research, positivist/postpositivist research, empirical research and postpositivism (Creswell, 2003).

Postpositivism reflects a determistic philosophy in which causes probably determines effects or outcomes. Thus, the problems studied by postpositivists reflect a need to examine causes that influences outcomes, such as issues examined in experiments. It is also reductionistic in that the intent is to reduce the ideas into a small, discrete set of ideas to test, such as the variables that constitute hypotheses and research questions. The knowledge that develops through a postpositivist lens is based on careful observation and measurement of the objective reality that exist out there in the world. Thus, developing numeric measures of observations become paramount for a postpositivist. Finally, there are laws or theories that govern the world, and these need to be tested or verified and refined so that we can understand the world. Thus, the scientific method is the accepted approach to research by postpositivits, that is, the researcher begins with a theory, collects data that either supports or refutes the theory, and then makes necessary revisions before additional test are conducted (Phillips and Burbules, 2000).

As earlier on indicated, the second element of inquiry on research design is the strategy of enquiry. In relation to that, Creswell (2007) indicated that there are three strategies namely; quantitative, qualitative and mixed methods. As earlier on highlighted, the researcher employed the quantitative strategy of inquiry for this research. Based on the above mentioned, quantitative research is explicitly linked to postpositivist. Campbell and Stanley (1963) indicated that, quantitative inquiry include true experiments, quasi-experiments and correlational studies. However, Campbell and Stanley (1963) endorsed the true experimental designs, which provides a higher degree of control in the experiment and produces a higher degree of validity. Williams (2007) indicated that, the true experimental designs result in a systematic approach to quantitative data collection involving mathematical models in the analysis.

In reference to the problem statement of the study, the main objective of the study is to compare early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* on mine tailings dump at Renco Mine. In this regard, the researcher attempts to generate knowledge which could make revegetation of mine tailings dumps more successful, efficient and sustainable. Therefore, the researcher intends to collect quantitative data by measuring growth performance on the species planted on the tailings dump as well as exploit mathematical models to reach to the conclusion. It is only through this process that the researcher would be able to conduct this study. At this point, the researcher employs a true experimental design for this research.

3.1.1 Experimental Design

An experiment is characterized by the treatments and experimental units to be used, the way treatments are assigned to units, and the responses that are measured (Oehlert, 2010). University of Southern California Libraries (2016) defined an experimental design as a blueprint of the procedure that enables the researcher to maintain control over all factors that may affect the result of an experiment. SAS (2005) indicated that, an experimental design specifies an experimental group and a control group. In relation to that, University of Southern California Libraries (2016) indicated that, the independent variable is administered to the experimental group and not to the control group, and both groups are measured on the same dependent variable. That is, the investigator can influence the number and the type of intervention. This is in contrast to the other types of studies called observational in which the events are not influenced by the investigator. In addition, Pandey et al. (2015) indicated that, subjects are randomly assigned to either the treatment or control group and are measured or tested both before and after the experimental treatment is implemented.

In this study, the research intends to demystify the traditional way of revegetation of mine tailings dumps through planting of different tree species on natural soil applied on mine tailings dumps as remedy. In most cases the practice is not successful because there is no baseline scientific information which may improve revegetation programs. According to Quinn and Keough (2012), experiments are conducted to provide specific facts from which general conclusions are established and thus involve inductive reasoning. Thompson and Panacek (2006) pointed out that, experimental design has remained consistent and is often the gold standard against which other designs are measured. It is against this background that, the researcher employs an experimental research which is scientific and is most suitable to the study.

In view of abovementioned, the researcher centered the design on the indicated hypotheses and objectives of the study in designing this research. Thus, *Dodonaea viscosa* and *Leucaena leucocephala* species were planted on Renco Mine tailings dump, and in this design the species are the experimental units. Two forms of soil type were applied as treatments remedy to the tailings material inside the planting holes for the experimental units. That is, the biosolids and natural soil obtained from topsoil nearby to the tailings dump. In this research, the treatment or experimental group is composed of biosolids soil type whilst natural soil stands as the control group. Oehlert (2010) indicated that, the control can be a convectional practice or common use or no intervention. As earlier on indicated, application of natural soil as remedy to tailings material has been the practice since revegetation exercise was started to rehabilitate the dump, therefore, the researcher decided to have natural soil as the control treatment or group. Oehlert (2010) added that, a control treatment is a standard treatment that is used as a baseline or basis of comparison for the other treatments.

Furthermore, the dump had two surface characteristics with regard to soil cover, that is, area covered with grass and the other part as bare ground. The bare area characterizes the upper part of the dump while the lower part is mainly characterized with grass cover. These two characteristics present different kind of environment on growth of species hence these were considered as blocks. SAS (2005) defined blocks as groups of experimental units that are formed to be as homogeneous as possible with respect to the block characteristics. SAS (2005) added that, the term block comes from the agricultural heritage of experimental design where a large block of land was selected for the various treatments that had uniform soil, drainage, sunlight, and other important physical characteristics. Montgomery (1997) mentioned that, most experimental designs require experimental units to be allocated to treatments either randomly or randomly in blocks. In view of this, it is more likely that species planted on grass covered ground have different physical characteristics as compared to the species grown on bare ground. The physical characteristics that may differ include terrain, organic material, moisture, rate of erosion and micro-organisms. Therefore, the researcher decided to have two blocks, that is, area covered with grass and the other part as bare ground.

Based on the above arrangement, two soil treatments (biosolids being the treatment or experimental group, and natural soil as the control group) assigned to two types of experimental units, that is, *Dodonaea viscosa* and *Leucaena leucocephala* on the tailings dump. Furthermore,

the research employed two blocks, that is, the experimental units with grass cover and bare ground (without cover).

3.1.1.1 Randomization

According to Oehlert (2010), randomization is the use of a known, understood probabilistic mechanism for the assignment of treatments to units. Randomization is the main tool to combat systematic and random error. Experiments must be designed so that we have an estimate of the size of random error. This permits statistical inference, for example, confidence intervals or test of significance. The success of randomization in various steps of an experiment protects against confounding is so overwhelming that randomization is almost universally recommended. Once we decide to use randomization, there is still the problem of actually doing it. Randomizations usually consist of choosing a random order for a set of objects (for example, choosing a subset of units for treatment A). Thus we need methods for putting objects into random orders and choosing random subsets (Oehlert, 2010).

In relation to the later, in this study the first stage of randomization was conducted on 500 planting holes. Thus, a card was randomly drawn from the hat with two cards inscribed "A" representing the block covered by grass, and "B" representing the bare ground block. The first card drawn was the first block to be filled up with the treatments followed by the other block. In a similar way, this first block was the first to be planted. At the same time, randomization was conducted for the two treatments. That is, two cards inscribed "1" representing the treatment group, and "2" representing the control group were placed in a hat and randomly drawn. Meaning, the first card drawn was the first treatment applied to the first planting hole starting with the lower row of a block then the second treatment type was applied to the next hole in the same row. In that alternating order all the planting holes were filled with the treatments even in the second row of the block. Similarly, because each block had two rows for two species, two cards inscribed "x" representing *Dodonaea viscosa* and "y" representing *Leucaena leucocephala* were drawn from the hat with the first card drawn taking lower first row then the second taking the second upper row in a block. Meaning, each row was planted with one type of species. This implies that, randomization for treatments and species was done separately for each block.

On the other end, the study worked with a population of 500 planting holes, meaning 250 planting hole for each of the two species. The species were nursed in a nursery at the tailings

dump. Thus, the researcher conducted randomization for both species to establish the random order in which the trees were drawn from the nursery to the planting stations. According to Oehlert (2010), physical generation of random orders is most easily done with cards or tickets in a hat. Oehlert (2010) illustrated that, take *N* cards, number them from 1 through to *N,* and mix them well, then the first object is then given the number of the first card drawn and so on. In relation to this, the researcher prepared and numbered 250 small cards from 1 to 250 for each type of species and mixed them thoroughly in a container. The first number withdrawn was assigned to the first nursed species with respect to existing order of rows inside the nursery shed. This procedure was followed up to the end for both species. Thereafter, the species were rearranged according to the new assigned random order numbers in increasing order. On the planting day, during the National Tree Planting Day, the trees were drawn in that random order and planted on the first randomly selected block.

3.2 SELECTION OF THE STUDY SITE AND PLANTING METHODS

The research was carried out on the southern side of an operational tailings dump at Renco Mine. A total area of 1.56ha with a rising slope of 22° on the dump was targeted for the study as shown in Figure 3.1. The area was selected because was earmarked for the tree planting season for year 2016-2017. Furthermore, a certain portion of the targeted area was planted *Cynodon dactylon* in 2006 which established ground cover on the dump. *Cynodon dactylon* characterizes the common grass species found in the natural ecosystem surrounding the mine dump. The researcher had to adopt this reserved area for the research. In line with this, *Dodonaea viscosa* and *Leucaena leucocephala* species were nursed by mine employee at the nursery located at the tailings dump. This follows a recommendation made by Kaphaizi (2015) that, species that characterized ecological succession on the old tailings dump can be extensively used for revegetation of an operational dump. Among the species that characterized ecological succession on the old dump was *Dodonaea viscosa* and *Leucaena leucocephala.*

Planting holes of 60 cm depth and 2 m in-row spacing were prepared on the terraced tailings dump. Pepper et al. (2003) pointed out that, the goals of revegetating mine tailings have to include the application of materials to amend the tailing substrate and provide an adequate environment for plant growth, for instance the use of biosolids. Accordingly, planting holes were each filled with either of the two treatment soil types as remedy to the tailings material and aid soil fertility as well as to support plant growth. Two rows with 125 planting holes each and an

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inter-row spacing of 2m were established on grass covered (*Cynodon dactylon*) area herein referred to as grass covered block. Similarly, two rows with same spacing were established on bare ground herein referred to as bare ground block. A total of 500 trees (250 species of *Dodonaea viscosa* and 250 species of *Leucaena leucocephala*) from the nursery at the dump were planted on these planting stations on the 6th of December 2017.

Figure 3.1: Renco Mine Tailings Dump Satellite Imagery

3.3 SAMPLING

Sampling means selecting a given number of subjects from a defined population as representative of that population (Pandey et al., 2015). Groves (2004) revealed that, the two main advantages of sampling are the faster data collection and lower cost. Meaning that, less time and money is required to study a sample than the whole population. On the other hand, Singh and Masuku (2014) indicated that, the basic role of statistics in research is to make conclusions about a population of interest when data is available from a sample. In this study, there are two elements to be sampled namely sampling of species and soil sampling. The populations of interests are the species which were subjects for measurement of early growth performance grown on two soil types. However, Singh and Masuku (2014) indicated that, the selection of

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sampling methods and determination of sample size are extremely important in applied statistics research problems to draw correct conclusions.

3.3.1 Sample Size Determination and Sampling of Species

The sample size should be carefully fixed so that it will be adequate to draw and generalized conclusions. The fixation of the adequate sample size requires specific information about the problems under investigation in the population under study (Singh and Masuku, 2014). Cornish (2006) revealed that, the greater the sample size the more statistically significant, however, a very large sample means even tiny deviations from the null hypothesis will be statistically significant.

In this comparative study, the researcher adopted Yamane (1967) formula to calculate sample sizes for the species in the study. The formula is given as follows:

$$\mathbf{n = N/[1+N(e)^2]} \qquad \qquad [1]$$

Where **n** is the sample size, **N** is the population size, and **e** is the level of precision. A 95% confidence level and p = 0.5 are assumed. This formula was supported by Glenn (1992) presenting tables for selection of sample sizes. In relation to this study, using the formula given above the researcher calculated and established a sample sized of 72 species as the sample size for each of the two species (*Dodonaea viscosa* and *Leucaena leucocephala*) at ±10% level of precision.

In terms of selecting species for the two samples, the research upheld randomization and used systematic random sampling. (Singh and Masuku, 2014) highlighted that, in this method of sampling, the first unit of the sample selected at random and subsequent units are selected in a systematic way. Meaning, if there are *N* units in the population and *n* units are to be selected, then *R = N/n* (the *R* is known as the sampling interval). The first number is selected at random out of the remainder of this *R* (sampling interval) to the previous selected number. In this study, the researcher applied a sampling interval of 3 species. Therefore, the first plant was randomly selected from the first 3 plants within the same treatment in the lower row by means of picking one small card from three cards mixed in a container inscribed "1", "2", and "3". Thus, other selected species of the same treatment then follows the systematic order by counting 3 species from the first selected plant. The selected plants were marked by assigning GPS coordinates for

locating the sample species during monitoring and measurement exercise in the course of the research.

3.3.2 Soil sampling

Ferguson et al. (2007) indicated that, the primary objectives of soil sampling are to determine the average nutrient status and degree of variability in a soil type. Ferguson et al. (2007) added that, correct nutrient management based on accurate information about soil fertility levels in soil, can result in increased plant growth performance, reduced cost and minimized environmental impact. The researcher was mainly interested in knowing nutrient status in two soil types used in this research study for the purpose of better soil fertility management in the revegetation program.

However, Patil (2002) stated that, high cost of laboratory analytical procedures frequently strain environmental and public health budgets. As a result Patil (2002) indicated that, composite sampling can substantially reduce analytical costs because the number of required analyses is reduced by compositing several samples into one and analyzing the composited sample. The researcher realized that both soil types used as treatments was stockpiled on the driveway in the mid-section of the dump near planting stations using a front-end loader and tractor. This form gave a homogeneity character whereby composite soil sampling can be applied. EPA (2005) defined composite soil sampling as a technique that combines a number of discrete samples collected from a body of materials into a single homogenized sample for the purpose of analysis. Therefore, due to cost saving in analyzing soil samples as well as the form of soil stockpiles, the researcher applied use of composite soil sampling.

According to EPA (2015), the principal limitation of composite sampling is the potential for hotspots to remain undiscovered due to the inherent characteristics of the process. For instance, a discrete subsample may contain a high concentration of contaminate that may be masked due to the dilution effect in the composite sampling procedure. To eliminate this limitation, the researcher adhered to the requirement of collecting same number and similar sizes of subsamples at equal depth to promote homogeneity of the samples. Meaning, each discrete subsample contributed an equal amount of soil material to the composite sample. The researcher ensured thorough mixing of the subsamples before extracting the final composite sample.

Furthermore, EPA (2015) indicated that, another challenge in collecting composite samples is that of site history of the points were the subsamples are extracted. That is, the only way to eliminate this limitation is to be certain on the site history. In the case of this research, the researcher was certain that biosolids material was obtained from the dry beds at the sewage treatment plant operated by the mine. The researcher obtained site history which refers that, the site for natural soil composite sample was extracted from the soil that was scrapped and piled during the construction of the tailings dump. That is, one elongated pile of soil was the collection point from where the tractor was drawing from then carrying to the dump.

In relation to the later, two distinct 500g composite soil samples were collected from two types of soil, that is, biosolids and natural soil for soil fertility analysis. Composite samples were collected from four stockpiles (two for each soil treatment) spread on different points of the dump. Each soil pile was approximately 6t in volume and cone shaped. Each soil pile was divided into four sections on the opposite sides right-round, and two sections on the top. Subsamples of 500g were extracted by boring on each section using an auger and plastic buckets. MDA (2017) illustrated that, each boring location is marked by an "X" and is identified by one or more of the three letters, that is, "B", "M" or "T" (a "B" means collect a subsample from the bottom third of the soil pile, a "M" means collect a subsample from the middle third of the soil pile, and a "T" means collect a subsample from the top third of the soil pile. The researcher used this illustrated approach as indicated in Figure 3.2.
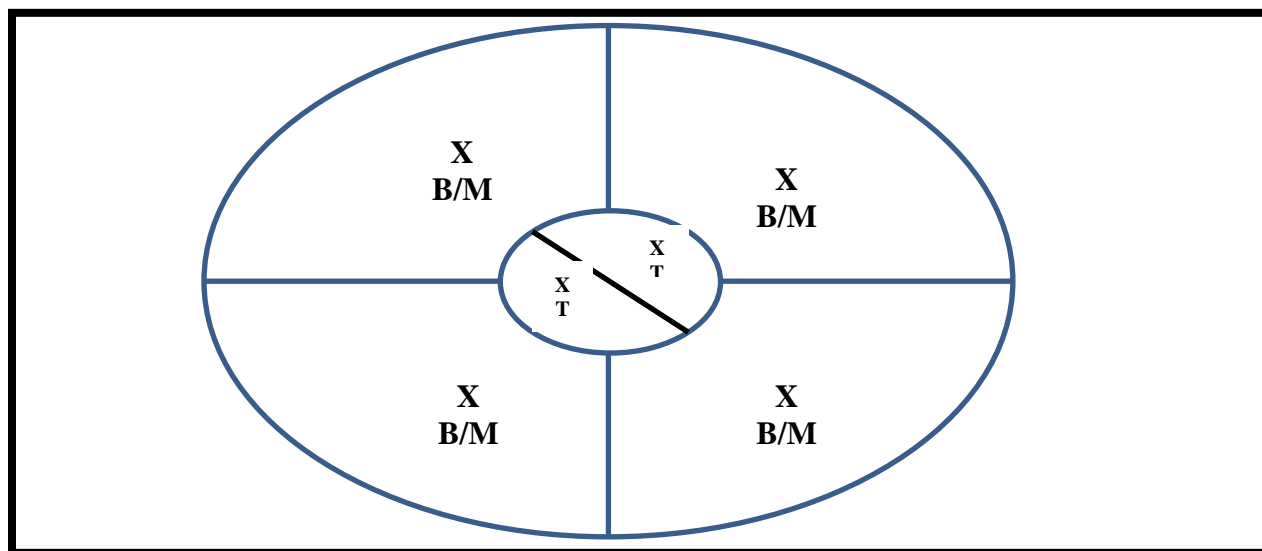
Figure 3.2: Cone Shaped Soil Pile Sampling Approach (Source taken from MDA (2017) *Soil Sampling Guidance*).

The sub-samples of the same treatment were thoroughly mixed in a plastic bucket and a composite sample was extracted then packed in plastic sample bags. The two composite samples labelled SWren17 (sample for Biosolids) and NSren17 (sample for Natural Soil) were sent to Scientific and Industrial Research and Development Centre (SIRDC) in Harare for soil fertility analysis.

3.4 DATA COLLECTION

The researcher used primary data collection research tools to collect data during the research study. Hox and Boeije (2005) defined primary data as data that are collected for the specific research problem at hand, using procedures that fit the research problem best. Hox and Boeije (2005) indicated that, on every occasion that primary data are collected, new data are added to the existing store of social knowledge. Increasingly, this material created by other researchers is made available for reuse by the general research community; it is then secondary data Hox and Boeije, 2005).

One major primary data collection strategy is the experiment. In an experiment, the researcher manipulates one or more independent variable following a planned design and observes the effects of the independent variables on the dependent variable, the outcome variable. The essence of an experiment is that the research situation is one created by the researcher. This permits strong control over the design and the procedure, and as a result the outcome of an experiment permits casual interpretation referred to as internal validity, that is, the degree to which the experimental design excludes alternative explanations of the experiment's results. This is different for secondary data collection whereby the researcher is required to locate data sources, retrieve the relevant data, and to evaluate how well the data meet the quality requirement of the current research (Hox and Boeije, 2005).

In line with the abovementioned, sampled species were measured in growth performance of height and root collar diameter using a flexible measuring tape and Vernier Caliper respectively. Initial measurements were collected soon after the day of planting. Thereafter, growth measurements were collected periodically over a period of 9 months, that is, after every 4 weeks starting from the 6th of December 2016, which was the planting date, up to the 31st of August 2017. Simultaneously, survival rates and rainfall measurements were also captured and recorded. In this case, the researcher had an opportunity to collect primary data in 3 seasons, namely,

summer, autumn and winter. Probably, the factor of seasonal changes on early growth performance of the plant species might be of importance to note.

3.5 DATA ANALYSIS

Data was analyzed separately for height, root collar diameter and survival rates using Analysis of Variance (ANOVA) for Randomized Complete Block Design (RCBD) model, and computation using Statistical Package for the Social Science (SPSS 16.0) for Windows and Microsoft Office Excel. Oehlert (2010) indicated that, the improvement of this design over a completely randomized design enables the researcher to make comparisons among treatments after removing the effects of a confounding variable, for instance in this case, different soil cover in blocks. Quinn and Keough (2012) indicated that, the linear model we fit to these data is an additive effects model, in which the response variable in each cell represents and an additive combination of factor A (treatments) and block effects and assuming there is no interaction between treatments and blocks. The additive model for the RCBD is:

$$\mathbf{Y_{ij} = \mu + \alpha_i + \beta_j + \xi_{ij}} \hspace{4cm} \textbf{[2]}$$

Where:

$\mathbf{Y_{ij}}$: is the value of the response variable from the ith treatment group and the $\mathbf{j^{th}}$ block

$\boldsymbol{\mu}$: constant overall population mean of the response variable

$\boldsymbol{\alpha_i}$: constant for the $\mathbf{i^{th}}$ treatment group; deviation from mean of $\mathbf{i}$

$\boldsymbol{\beta_j}$: constant for the $\mathbf{j^{th}}$ block; deviation from the mean of $\mathbf{j}$

$\boldsymbol{\xi_{ij}}$: random deviation associated with each observation

Table 3.1: RCBD Table

Treatments		Sub Sample	Blocks		Treatment Total $(Y_{i..})$	Treatment Mean $(\ddot{Y}_{.j.})$
			1	2		
			Grass Cover	Bare Ground		
1	**Biosolids**	1 *(Dodonaea viscosa)*	Y_{111}	Y_{121}		
		2 *(Leucaena leucocephala)*	Y_{112}	Y_{122}		
		$Y_{1j.}$	**Y_{11}**	**Y_{21}**	**$(Y_{1..})$**	**$(\ddot{Y}_{.j.})$**
2	**Natural Soil**	1 *(Dodonaea viscosa)*	Y_{211}	$Y2_{21}$		
		2 *(Leucaena leucocephala)*	Y_{212}	Y_{222}		
		$Y_{2j.}$	**Y_{12}**	**Y_{21}**	**$(Y_{2..})$**	**$(\ddot{Y}_{.j.})$**
Block Total $(Y_{.j.})$			**$(Y_{.1.})$**	**$(Y_{.2.})$**	**$(Y...)$**	-
Total Block Mean $(\ddot{Y}_{.j.})$			**$(\ddot{Y}_{.1.})$**	**$(\ddot{Y}_{.2.})$**	-	**$(\ddot{Y}_{...})$**

Missing observations are potentially a big problem for RCBD because a single missing observation is, in effect, a missing cell (Quinn and Keough, 2012). Reason for missing data includes complete wilting of plant species. Snedecor and Cochran (1989) proposed a method to estimating missing values based on the assumption of additivity, and use available information from the same treatment and block. Quinn and Keough (2012) indicated that, whenever estimating a value then one degree of freedom (df) should be subtracted from the residual for each substituted value. As stated by Quinn and Keough (2012), data that was missing j in an experimental group i in a RCBD was estimated using information from Table 3.1 as follows:

$$*Y_{ij} = (aA_i + bB_j - \sum\sum Y_{ij})/(a-1)(b-1) \qquad [3]$$

Where:

$*Y_{ij}$: is the estimated mean in **i**[th] treatment of **j**[th] block

A_i: is the sum of Means in **i**[th] treatments with a missing mean

B_j: is the Sum of Means in **j**[th] block with a missing mean

a: number of treatments

b: number of blocks

Furthermore, according to Quinn and Keough (2012), a two-way ANOVA is useful when we desire to compare the effect of multiple levels of two factors and we have multiple observations at each level. Therefore, since the researcher dealt with multiple levels of two treatments, a two-way ANOVA in RCBD was used, $\alpha = 0.05$ significance level.

3.5.1 Rejection Criteria

Hypothesis 1: H$_0$ was rejected when $F_{cal} > F_{(0.05: (a-1)(b-1), ab(n-1))}$ or $p < 0.05$, and failed to reject **H$_0$** when $F_{cal} < F_{(0.05: (a-1)(b-1), ab(n-1))}$ or $p > 0.05$.

Hypothesis 2: H$_0$ was rejected when $F_{cal} > F_{(0.05: a-1, ab-1)}$ or $p < 0.05$, and failed to reject **H$_0$** when $F_{cal} < F_{(0.05: a-1, ab-1)}$ or $p > 0.05$.

Hypothesis 3: H$_0$ was rejected when $F_{cal} > F_{(0.05: b-1, ab-1)}$ or $p < 0.05$, and failed to reject **H$_0$** when $F_{cal} < F_{(0.05: b-1, ab-1)}$ or $p > 0.05$.

3.5 DATA PRESENTATION

In the production of a comprehensive research, the researcher presented data graphically using simple bar graphs, pie charts and tables. Thereafter, discussion of the presented results was made in line with the research findings.

3.6 ETHICAL CONSIDERATIONS

Johnstone (2009) suggests that, ethics is a branch of philosophy which deals with the dynamics of decision making concerning what is right and wrong. Fouka and Mantzorou (2011) indicated that, scientific research work, as all human activities, is governed by individual, community and social values. In this regard, research ethics relates to moral standards that the researcher should consider in all research methods in all stages of the research design. Fouka and Mantzorou (2011) stated that, research ethics involve requirements on daily work, the protection of dignity of subjects and the publication of the information in the research. It is against this background that, the researcher was committed to follow research ethics relative to this research study.

According to Armiger (1997), informed consent is the major ethical issue in conducting research. As such, after obtaining the approval to conduct the study from Midland State University, the researcher tendered a letter of request to the Human Resources Superintendent requesting to

carry out a research study at Renco Mine tailings dump. The researcher also engaged the Plant Superintendent who oversees operation of the tailings dump. Thereafter, the researcher was permitted to proceed in carrying out this research study.

Fouka and Mantzorou (2011) indicated that, research should consider the principle of beneficence. Beauchamp and Childress (2001) suggest that, the principle of beneficence includes the professional mandate to do effective and significant research so as to better serve and promote the welfare of our constituents. In this regard, the researcher indicated that, the results and findings of the research were set benefit more the on-going rehabilitation exercise on the tailings dump at Renco Mine. In relation to that, the researcher made a request to collect soil samples used for soil fertility at the tailings dump. The researcher indicated that the samples were going to be sent to SIRDC for soil fertility analysis. This was necessitated by the need to drive the objectives of the study.

In addition, Fouka and Mantzorou (2011) indicated that the researcher is responsible to maintain confidentiality. In reation to that, the researcher indicated that research findings were going to be used for academic purpose as such research information was going to be treated with higher levels of confidentiality.

On the other hand, Jameton (1984) stated that, one of the most imporatnt element in research is competency of the researcher. In relation to this, the researcher was under direct supervision of a Midlands State University lecturer to guide the research study. Furthermore, during the time of the resesarch, the researcher was employed at the mine as a Health, Safety and Environment Officer since year 2013 with vast of field experience particularly at the respective mine tailings dump. In addition, the reseacher carride out a research on ecological succession on the old tailings dump at Renco Mine gaining more insight in rehabilitation of mine tailings dumps. Based on this experience, it is relatively considerable that the researcher had some competetnce in the line of study.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 RESULTS OVERVIEW

Generally, *Dodonaea viscosa* planted on biosolids on grass covered area exhibited the highest overall monthly mean height increment of 3.1 cm with monthly growth increment interval of 3.1± 1.45cm as shown in Figure 4.1. This was followed by *Leucaena leucocephala* planted on biosolids with grass cover recording an overall monthly mean height increment of 2.27 cm with monthly growth increment interval of 2.27 ± 1.11cm. As presented by Figure 4.1, lower height increments were recorded on *Leucaena leucocephala* planted on natural soil both on bare ground and grass covered area with monthly mean height increments of 1.1cm and monthly growth increment intervals of 1.1 ± 1.80cm and 1.12 ± 0.94cm respectively. Similarly, another lower monthly mean height increment of 1.1cm was recorded on *Leucaena leucocephala* planted on biosolids without soil cover with a monthly mean height increment interval of 1.12 ± 1.02cm.

Overall Monthly Mean Height Increments (cm) Intervals (at 95% Confidence Interval)

	Grass cover	*Bare ground*	*Grass cover*	*Bare ground*	*Grass cover*	*Bare ground*	*Grass cover*	*Bare ground*
	Natural Soil		*Biosolids*		*Natural Soil*		*Biosolids*	
	Dodonaea viscosa				*Leucaena leucocephala*			
◆ *Mean (cm)*	2.03	1.71	3.10	1.98	1.12	1.10	2.27	1.11
Upper Limit (cm)	3.27	3.29	4.55	3.79	2.06	1.90	3.38	2.13
- *Lower Limit (cm)*	0.78	0.13	1.66	0.17	0.18	0.30	1.16	0.09

Figure 4.1: Overall Average Height Increments (cm) Intervals

Additionally, species thriving on biosolids soil treatment displayed higher monthly mean height increments as compared to plants planted on natural soil as shown in Figure 4.2 and Figure 4.3 in relation to estimated marginal means. More so, species thriving in area with grass surface cover exhibited higher monthly mean height increments as compared to plants planted uncovered surfaces. In relation to that, *Dodonaea viscosa* showed higher estimated marginal means of height increments on both soil types and cover as compared to *Leucaena leucocephala.*
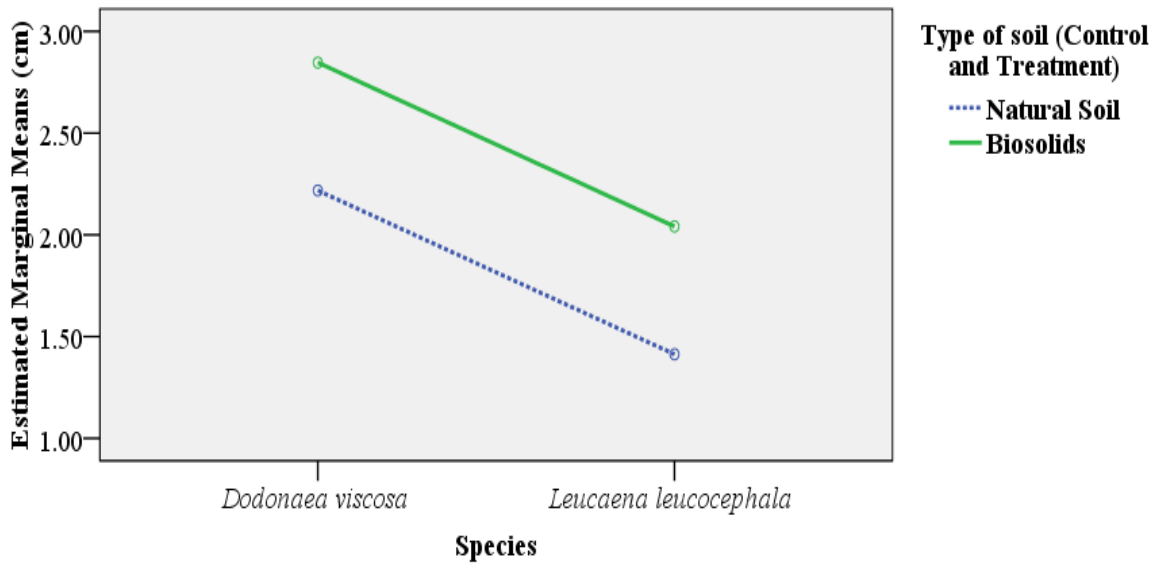
Figure 4.2: Estimated Marginal Means of Monthly Average Height Increments on Grass Cover
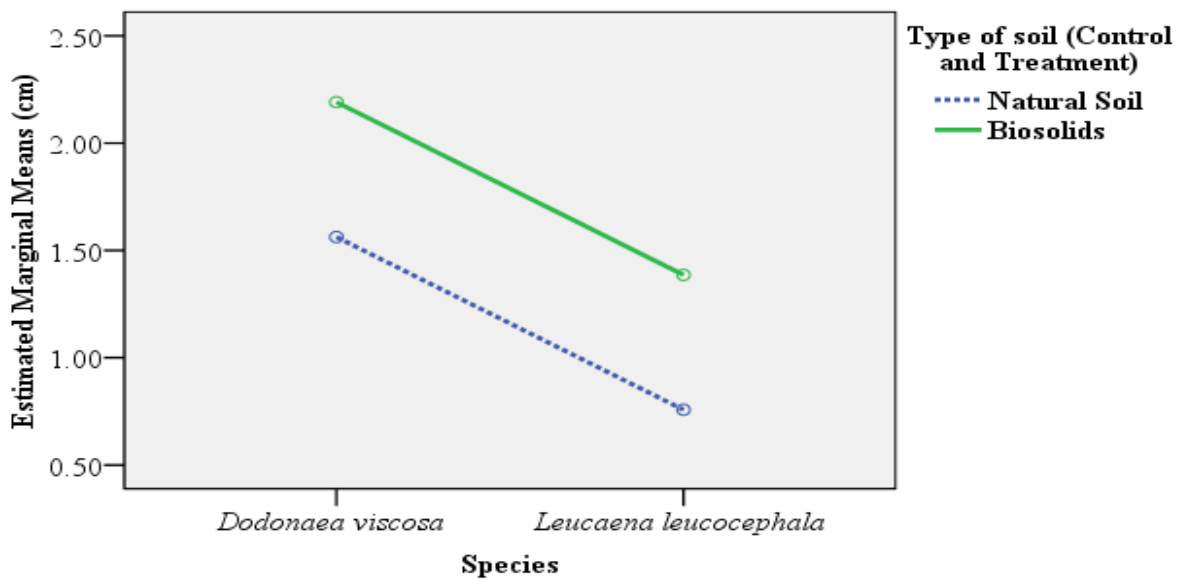
Figure 4.3: Estimated Marginal Means of Monthly Average Height Increments on Bare ground

Overall Monthly Mean Root Collar Diameter Increments (cm) Intervals (at 95% Confidence Interval)

	Grass cover	Bare ground	Grass cover	Bare ground	Grass cover	Bare ground	Grass cover	Bare ground
	Natural Soil		Biosolids		Natural Soil		Biosolids	
	Dodonaea viscosa				Leucaena leucocephala			
Mean (cm)	0.02	0.02	0.03	0.02	0.02	0.01	0.03	0.01
Upper Limit (cm)	0.04	0.05	0.05	0.04	0.03	0.03	0.05	0.03
- Lower Limit (cm)	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00

Figure 4.4: Overall Average Root Collar Diameter Increments (cm) Intervals

The overall monthly mean root collar diameter (RCD) was high on both *Dodonaea viscosa* and *Leucaena leucocephala* planted on biosolids covered with grass as presented in Figure 4.2. The monthly average intervals were 0.03 ± 0.02cm on both species. Some species planted on bare ground on both soil types showed stranded growth as shown in Figure 4.2 with lower bounds of monthly mean increments on root collar diameter not changing at all. In general, root collar diameter changes were attributed to ground cover though species on biosolids recorded higher increments.

Likewise, species thriving on biosolids soil treatment displayed higher monthly mean RCD increments as compared to plants planted on natural soil as shown in Figure 4.5 and Figure 4.6 in relation to estimated marginal means. Furthermore, species thriving in area with grass surface cover exhibited higher monthly mean RCD increments as compared to plants planted uncovered surfaces. Generally, *Dodonaea viscosa* showed higher estimated marginal means of RCD increments on both soil types and cover as compared to *Leucaena leucocephala.*
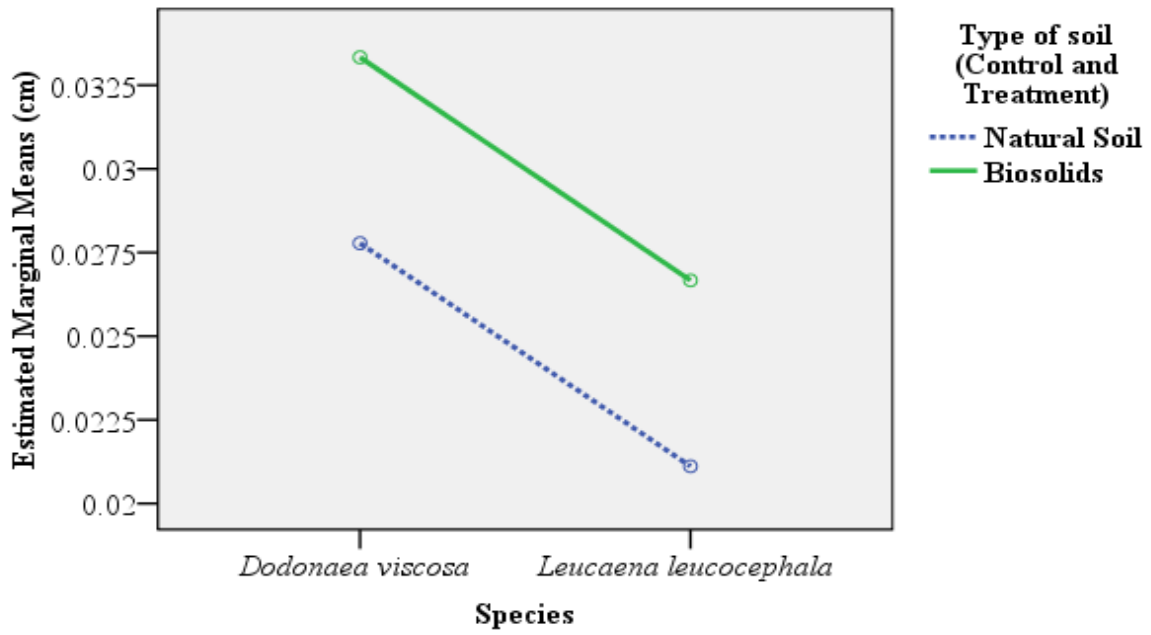
Figure 4.5: Estimated Marginal Means of Monthly Average RCD Increments on Grass Cover
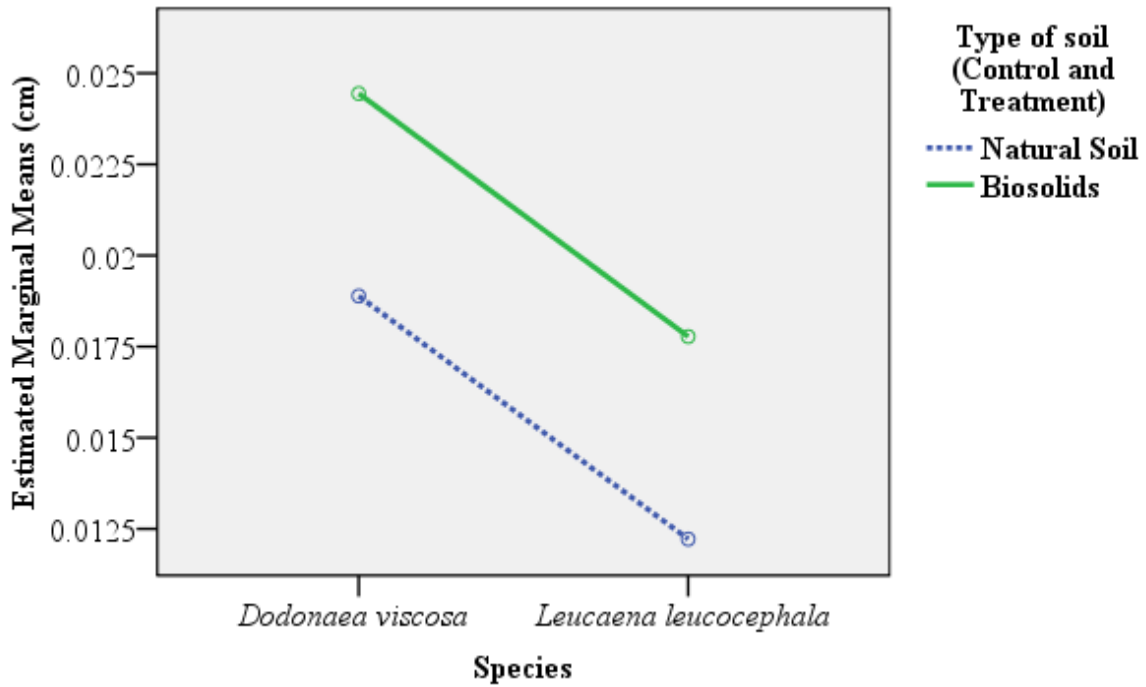
Figure 4.6: Estimated Marginal Means of Monthly Average RCD Increments on Bare ground

In overall, survival rate of 66.7% for *Dodonaea viscosa* planted on biosolids soil treatment on grass covered ground was the highest. This was followed by *Leucaena leucocephala* planted on biosolids soil treatment on grass covered ground with a survival rate of 61.1%. Lowest survival rates were recorded on *Leucaena leucocephala* planted on natural soil on both bare ground and grass covered with survival rates of 22.2% and 33.3% respectively. Similarly, lower survival rates for *Dodonaea viscosa* were recorded on natural soil both on bare ground and grass covered with rates of 33.3% and 38.9% respectively.

Basically, species planted on biosolids recorded high survival rates as compared to species planted on the natural soil. In addition to that, it was noted that species planted on covered ground recorded better survival rates than species on bare ground. In general, *Dodonaea viscosa* showed better survival rates than *Leucaena leucocephala.*

Species Survival Rates (%)

	Dodonaea viscosa				Leucaena leucocephala			
	Grass cover		Bare ground		Grass cover		Bare ground	
	Natural Soil	Biosolids	Natural Soil	Biosolids	Natural Soil	Biosolids	Natural Soil	Biosolids
■ Survival Rates (%)	38.9	66.7	33.3	50	33.3	61.1	22.2	38.9
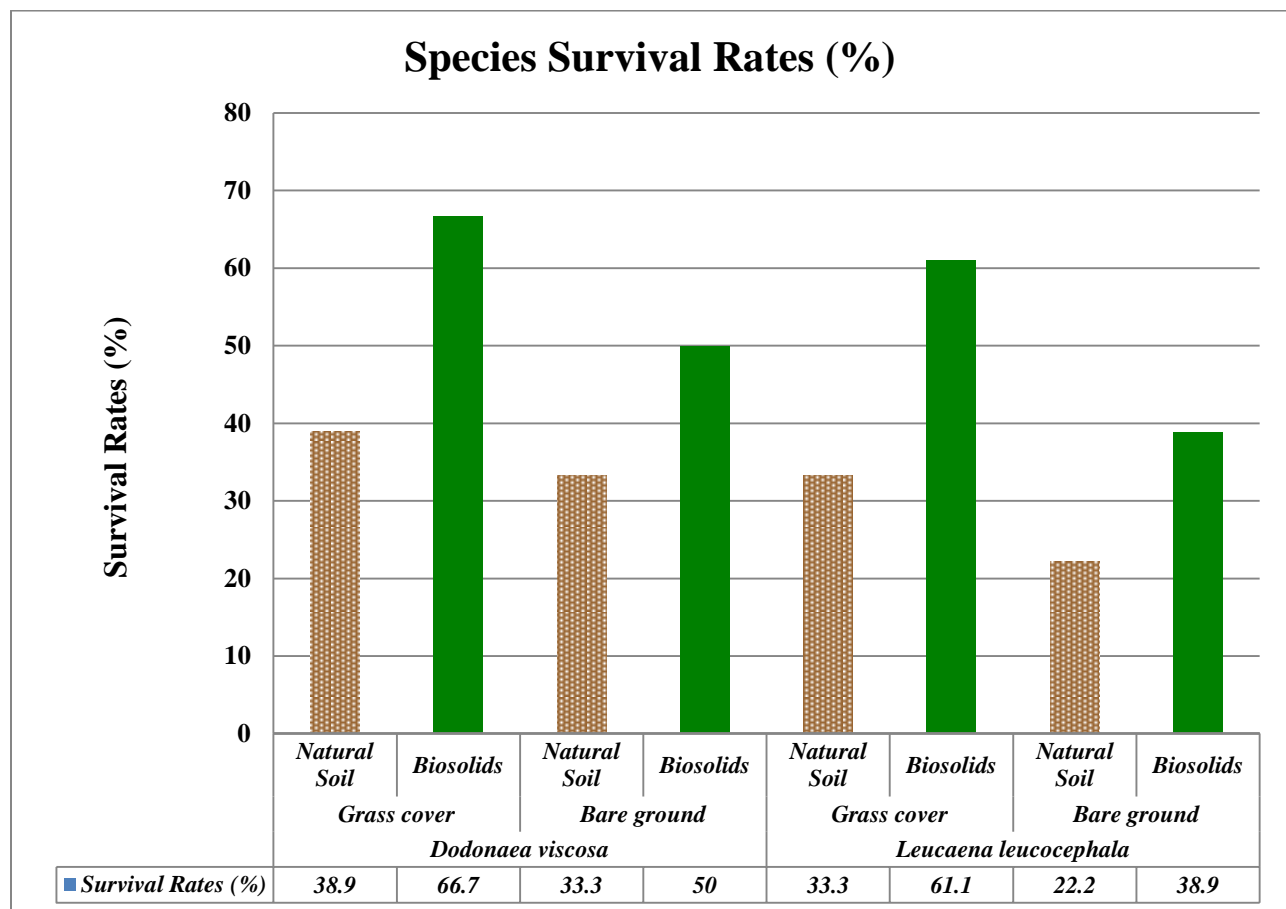
Figure 4.7: Recorded Survival Rates (%) as at 31 August 2017

4.2 GROWTH PERFORMANCE ANALYTICAL RESULTS

4.2.1 Height and Root Collar Diameter

Table 4.1: ANOVA of RCBD for Monthly Average Height Increments (cm) of Species

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	26.506	3	8.835	18.793	.000	1.000
Intercept	233.784	1	233.784	497.269	.000	1.000
Species	11.664	1	11.664	24.811	.000	.998
Cover	7.736	1	7.736	16.454	.000	.979
Soil	7.106	1	7.106	15.116	.000	.969
Error	31.969	68	.470			
Total	292.260	72				
Corrected Total	58.476	71				

Based on results presented in Table 4.1 and Table 4.2 on monthly average height increments and root collar diameter (RCD) increments of species respectively, at α = 0.05 significance level, in both cases p < 0.05. That is, α = 0.998 for monthly average height increments, and α = 0.758 for monthly average RCD increments. Therefore, there was enough evidence to conclude that, there was a significant statistical difference in early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* on mine tailings dump**.** This is in agreement with results presented on estimated marginal means for both height and root collar diameter. Growth rates for *Dodonaea viscosa* were relatively better as compared to early growth performance of *Leucaena leucocephala*

Table 4.2: ANOVA of RCBD for Monthly Average RCD Increments (cm) of Species

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	.003	3	.001	8.433	.000	.991
Intercept	.037	1	.037	340.202	.000	1.000
Species	.001	1	.001	7.286	.009	.758
Cover	.001	1	.001	12.952	.001	.944
Soil	.001	1	.001	5.060	.028	.602
Error	.007	68	.000			
Total	.048	72				
Corrected Total	.010	71				

Furthermore, Singh (2015) indicated that, early growth performance of *Leucaena leucocephala* on mine tailings is poor. Conversely, Rani et al. (2009) indicated that, *Dodonaea viscosa* tolerates sandy or rocky soils, salt spray, windy areas and drought conditions, and it favors areas that receive full sun and is often cultivated in loamy or sandy soils. In light to this, the results obtained by the researcher as presented in Figure 4.2 and Figure 4.3, are in agreement with this remark, early growth performance of *Leucaena leucocephala* was less to that of *Dodonaea viscosa*. This also applies to results presented if Figure 4.5 and Figure 4.6. In view of this, the researcher recommended that, *Dodonaea viscosa* can be extensively be used in revegetation of mine tailings dump at Renco mine due to its early growth adaptability. The researcher added that, *Leucaena leucocephala* can also be used with aided nursing such as regulating pH during early growth stages. Furthermore, Orwa et al. (2009) indicated that, *Leucaena leucocephala* has high nitrogen-fixing potential related to its abundant root nodulation, and as indicated by Yang et al. (2003) that, nitrogen is a major limiting nutrient on mine tailings dumps. The researcher recommends continued use *Leucaena leucocephala* as the species has potential to address the deficit of nitrogen on mine tailings.

4.2.2 Effect of Treatment and Control

In reference to results presented in Table 4.1 and Table 4.2 in relation to soil type (treatment and control), at $\alpha = 0.05$ significance level, in both cases $p < 0.05$. That is, $\alpha = 0.969$ for monthly average height increments, and $\alpha = 0.602$ for monthly average RCD increments. Therefore, there was enough evidence to conclude that, there was significant statistical difference in early growth performance of *species* on different soil treatments applied on mine tailings dump.

Though the results presented in Table 4.3 indicates that, both soil samples were acidic, both species especially *Dodonaea viscosa* thrived well on biosolids soil material than in natural soil. As shown in Table 4.3 biosolids were high in N and P as compared to natural soil. This was in agreement with Forge et al. (2006) stating that, biosolids are good sources of N, P, and micronutrients for short term crop production. Even, *Leucaena leucocephala* relatively grew better on biosoilds as compared to the natural soil. This finding was similar to a study at the Mission Mine in Arizon, whereby Pepper et al. (2003) indicated that, application of biosolids can be a feasible revegetation strategy.

It was established that, pH was low in both soil types. Lake (2000) pointed out that, the effect of soil pH is great on the solubility of minerals or nutrients, and most minerals and nutrients can be soluble or available in acid soils than neutral or slightly alkaline soils. However, Mashakada (2001) pointed out that, extremely and string acid soils (pH 4.0 – 5.0) may be toxic to the growth of some species. In view of this, *Leucaena leucocephala* could have been greatly affected in both soils than *Dodonaea viscosa* which appeared to be tolerant of the condition. However, due to low pH found in the biosolids, the researcher suggest that, testing of pH should be done before using any soil type for planting trees on mine tailings dumps, and remedy should be done in order to reach correct pH levels.

4.2.3 Effect of Soil Cover

As presented in Table 4.1 and Table 4.2 in relation to soil cover, at $\alpha = 0.05$ significance level, in both cases $p < 0.05$. That is, $\alpha = 0.979$ for monthly average height increments, and $\alpha = 0.944$ for monthly average RCD increments. Therefore, there was enough evidence to conclude that, there was difference in early growth performance of *species* on grass covered soil and bare soil on mine tailings dump**.**

There were higher monthly mean heights and RCD increments on both species planted on areas covered by grass species (*Cynodon dactylon)* as compared to bare ground. The researcher attributed this positive increase as alluded by Ranjan et al. (2015) stating that, roots of grasses are fibrous that can slow erosion, and their soil forming tendencies eventually produce a layer of organic soil, stabilize soil, conserve soil moisture and may compete with weedy species. In line with this, Shu et al. (2002) mentioned that, the initial cover from grasses allows the development of diverse self-sustaining plant communities. Furthermore, Ranjan et al. (2015) indicated that, grasses are considered as a nurse crop for an early vegetation purpose. Therefore, the researcher noted positive impact of grass cover on early growth performance of species planted on mine tailings at Renco Mine. However, the researcher recommends further investigation on the type of grass species for use in establishing ground cover and a nurse for tree seedlings.

4.3 PLANT-SOIL FERTILITY ANALYSIS

Soil pH was strongly acidic in both samples as shown in Table 4.3. In relation to that, Grange (1973) pointed out that, a wide range of plant communities can survive on soil that have pH from 5.0 or high. In addition to that, Mashakada (2001) mentioned that, whenever pH is as low as 3 or

as high as 8 there are always nutrient availability problems, and dramatically reduce plant growth. Lake (2000) also indicated that, at a low pH, beneficial element such as molybdenum (Mo), phosphorus (P), magnesium (Mg) and calcium (Ca) become less available to plants. Lake (2000) added that, other elements such as Al, Fe, and Mn may become more available and Al and Mn may reach levels that are toxic to plants. Lake (2000) recommended that, lime is usually added to acid soils to increase soil pH. Lake (2000) added that, lime also provides two nutrients, Ca and Mg, and makes P that is added to the soil more available for plant growth as well as increases availability of N by hastening the decomposition of organic matter. In contrast, when the pH is greater than 7.5, Ca can tie up P, making it less available to plants, and may cause Zn and Co deficiencies that lead to student plants and poor growth (Lake, 2000). In that regard, Mashakada (2001) recommends that, due to fact that soil pH changes over time, monitoring pH changes over time is an important management tool, that is, past and present soil tests, assist to prevent soil from becoming more acidic or alkalinity.

Table 4.3: Soil Fertility Test Results obtained from SIRDC

Sample Ref	pH 0.01M CaCl$_2$	Potassium (K) (Meq/100g) NH$_4$Cl Extractable	Calcium (Ca) (Meq/100g) NH$_4$Cl Extractable	Magnesium (Mg) (Meq/100g) NH$_4$Cl Extractable	Phosphorous (P) (ppm) Resin Extractable	Initial Nitrogen (N) 1M KCL Extractable
SWren17	3.85	0.01	4.10	0.16	80.02	35.03
NSren17	4.48	0.01	5.08	0.19	7.06	24.52

In relation to that, Orwa et al. (2009) pointed out that, *Leucaena leucocephala* performs optimally on calcareous soils but can be found on saline soils and on alkaline soils; it is not tolerant of acid soils. Orwa et al. (2009) added that, *Leucaena leucocephala* is known to be intolerant of soils with low pH, low phosphorus, low calcium and high salinity, and has often failed under such conditions. On the other hand, Gilman (2014) pointed that, *Dodonaea viscosa* can thrive in acidic and alkaline, sandy and loamy conditions, and the species is drought tolerant. Similarly, Pearman (2000) indicated that, *Dodonaea viscosa* is tolerant of salinity, drought and pollution. This implies that, as shown by the results on growth performance, *Dodonaea viscosa* thrived better in both soil conditions which were acidic in nature as compared to *Leucaena leucocephala.* Furthermore, in reference to Figure 4.7, low survival rates of below 33.3% to the lowest of 22.2% as depicted can be attributed to acidic conditions of both soil applications. In view of this, the researcher strongly recommends liming application for continual use of the two soil types.

Nitrogen and Phosphorus were very high in content in the biosolids than in the natural soil. The results were in agreement with Forge et al. (2006) stating that, municipal biosolids are good sources of N, P, and micronutrients for short term crop production. In relation to that, EPA (2006) indicated that, tailings materials are generally be described as having potentially low levels of plant available nutrients such as N and P, therefore, it is advantageous to have high value of N and P in the remedial soil for plant growth and development. However, Rorison (1977) revealed that, *Nitrosomonas* and *Nitrobacter,* which are largely responsible for nitrification of ammonia to nitrite and nitrite to nitrate, are very poorly active at lower pH. Uchida (2006) indicted that, nitrogen is taken by plants an ammonium (NH^{+4}) and nitrate (NO^{-3}) ions, and is a vital constituent of amino acids in proteins and nucleic acids used in forming protoplasm, the site for cell division and thus for plant growth and division. Thus, due to low pH results, the researcher greatly attributed stranded growth and survival of *Leucaena leucocephala* to low pH as the microorganisms responsible for conversion of nitrogen to NH^{+4} and nitrate NO^{-3} probably were not active in this condition. Similarly, the researcher strongly recommends liming application for continual use of the two soil types.

However, low soils quantity of P in the natural soil was of great concern. Uchida (2000) indicated that, phosphorus plays a major role in energy storage and transfer, and aids in root development. In view of that, stranded growth of species planted on natural soil was attributed to the fact that probably the species were prone to slow root development hence triggering slow growth rates. The researcher remarked that, slow root developments ultimately have a smaller surface area for uptake of plant mineral nutrients implying that less nutrients were obtained by plants on this soil application resulting to slower growth rates. Therefore, the researcher suggested that, application of phosphorus fertilizers would address the challenge in this regard.

Traces of K, Ca, and Mg elements, which are also vital minerals for various plant metabolism processes, were recorded from both soils. Schwartzkopf (1972) pointed that, K is absorbed by plants in larger amounts than any other element except N and Ca. it is needed for the plant cell's metabolic processes and apparently has a role in influencing the action of enzymes, as well as in aiding the synthesis and translocation of carbohydrates. SIRDC (2017) revealed that, the quantity of potash was relatively suitable for plant growth. Therefore, both species stood the opportunity to utilized available K. Schwartzkopf (1972) also indicated that, Ca is an extremely important

mineral in plant nutrition; basically its key role is on the development of cell walls and in root development. According to Schwartzkopf (1972), Mg plays a vital role in photosynthesis, as it is the central atom in the chlorophyll molecule. However, the researcher noted that little has to be done to maintain or improve quantities of K, Ca and Mg.

4.4 RAINFALL DISTRIBUTION

As shown in Figure 4.1, rainfall distribution was positively skewed. According to Leishman and Westoby (1994), early seedling growths are highly susceptible to changes in climatic conditions such as rainfall. Hsiao (1973) indicated that, decline in plant growth can be due to water limitations which inhibit cell expansion and division.

In relation to the recorded rainfall, Orwa (2009) indicated that, *Leucaena leucocephala* is not tolerant to waterlogging conditions. It was realized that, Since December 2016 up to March 2017 severe wet conditions mainly characterized the rainfall pattern and distribution. Somehow, the researcher noted that, this condition was not suitable for *Leucaena leucocephala* to thrive well.

Recorded Volume of Rainfall (mm): December 2016 - August 2017

	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17
Rainfall (mm)	210	243	165	126	78	11	3	5.6	10
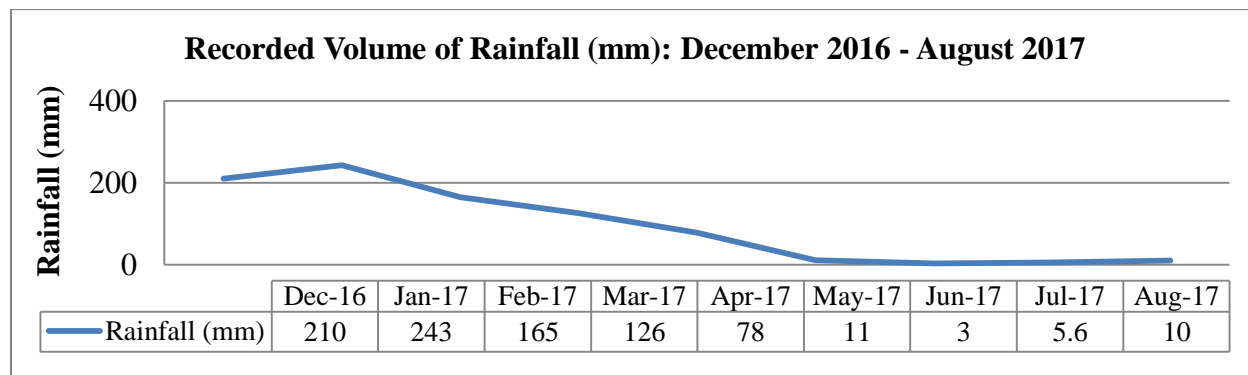
Figure 4.8: Recorded Volume of Rainfall (mm) as from December 2016 - August 2017

The study location started to receive low amounts of rainfall beginning of May 2017, and since the revegetation exercise is rain fed, drought conditions prevailed from May 2017 to August 2017 and so on. Uchida (2000) stated that, K is known to improve drought resistance by assisting in regulating the plant's use of water by controlling the opening and closing of leave stomata, were water is released to cool the plant, and uptake of water from the roots. In view of this, as indicated by Pearman (2000) that, *Dodonaea viscosa* is tolerant of drought it becomes more beneficial to regulate water use in the species. The researcher attributed the higher survival rate of 66.7% for *Dodonaea viscosa* to the suitable extractable soil K.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In overall, *Dodonaea viscosa* planted on biosolids on grass covered area thrived well. The same trend was noted on *Leucaena leucocephala*, with its higher growth rates recorded on biosolids with grass cover. However, lower growth rates were recorded on *Leucaena leucocephala* planted on natural soil both on bare ground and grass covered. Highest survival rate was recorded on *Dodonaea viscosa* planted on biosolids soil treatment on grass covered ground. Relatively higher survival rate for *Leucaena leucocephala* was also obtained on biosolids soil treatment on grass covered ground. Lowest survival rates were recorded on *Leucaena leucocephala* planted on natural soil on both bare ground and grass covered. In addition to that, there were higher monthly mean heights and RCD increments on both species planted on areas covered by grass species (*Cynodon dactylon)* as compared to bare ground. The researcher attributed this positive increase to the conditions set by grass roots such as soil forming tendencies which eventually produce a layer of organic soil, stabilization of soil, and soil moisture retention may compete with weedy species.

In general, both soil treatments were acidic, biosolids were high in N and P as compared to natural soil, and traces of K, Ca, and Mg elements, which are also vital minerals for various plant metabolism processes, were noted from both soils. However, both species especially *Dodonaea viscosa* thrived well on biosolids soil material than in natural soil. *Leucaena leucocephala* relatively grew better on biosoilds as compared to the natural soil. The researcher concluded that, *Dodonaea viscosa* can be extensively used in rehabilitation of mine tailings dump at Renco Mine as the species shown potential to thrive in hostile conditions found on mine tailings. *Leucaena leucocephala* can be relatively used with ameliorative measures on soil especially soil pH. The researcher suggested that, grasses should be considered for use to provide nurse for early vegetation purpose. Based on the account of the study, the researcher concluded that, species planted on biosolids with grass cover recorded high growth and survival rates as compared to species planted on the natural soil.

5.2 RECOMMENDATIONS

The establishment of vegetation on mine tailings dump is the main thrust of revegetation of mine tailings dumps. During this research, the researcher focused on early growth performance of *Dodonaea viscosa* and *Leucaena leucocephala* planted on different soil types applied on an operational mine tailings dump at Renco Mine. Furthermore, the researcher compared growth performances of these species on different soil cover. However, the researcher realized that there were other factors which may complement the thrust of successfully establishing vegetation in the revegetation of mine tailings dumps. In view of that, the researcher made the following recommendations.

- Based on the results obtained from soil fertility analysis, the researcher recommends that further full soil fertility analysis should be carried out from soil were indigenous species are thriving in the natural vegetation. This will ensure better soil treatment conditions which should be achieved or to form baseline of suitable conditions for growth of respective native species.

- In addition, the researcher greatly recommends that, there in need to apply liming fertilizer on both soil types in addressing low pH levels which are associated with plant-nutrient uptake challenges. For instance application of gypsum. Many plant species thrive well in the range of pH of 5 to 8. The research suggests that, pH test should be done before using any soil type for planting trees on mine tailings dumps.

- Based on the results of the research, the researcher recommended that, grass species should be planted first to establish an initial ground cover on mine tailings dumps before introducing tree species. Survival rate of tree seedlings planted on a mine tailings dump is most likely to be higher on grass covered area as compared to bare area. Vegetation has an important role in protecting the soil surface from erosion and allowing accumulation of soil organic matter, total N, available P, available K, and increased water retention capacity.

- In relation to the later, the researcher recommends that, further investigations have to be made on studying different types of grass species which may compete less for plant-soil nutrients with tree seedlings which may be planted as a nurse to establish ground cover. It has been established that, grass species compete with trees for water and nutrients in a number of

ecosystems which may limit tree growth. The researcher suggests that, grass species found in the respective local surroundings are the most ideal for this kind of a study.

- The researcher recommends that, there is need to continue to investigate growth and survival performance of other indigenous species found in the respective local surrounding. For instance, legume species which play an important role of nitrogen fixation. Native or locally acclimatized plants are commonly chosen for long-term vegetation in order to re-establish an ecological situation similar to that prevailing before the mine was developed. Use of adaptive native species is more sustainable and promotes restoration of the ecosystem that was in existence before establishment of the mine dump.

- Although the researcher managed to carry out this study fitting in three different climatic seasons over a period of nine months, the researcher recommends longer studies in order to get more substantial results. The researcher suggest that, further research after early growth performance have to be carried out over years of establishment to get more validated resource information for further revegetation exercises. For instance, studies which can be carried over a period of a decade are more likely to show a broader insight on growth performance of species.

- The researcher also recommends that, *Dodonaea viscosa* can be extensively used in revegetation of mine dumps. As established during the study, *Dodonaea viscosa* shown the ability to thrive on a mine dump on both soil types (biosolids and native soil), and even shown a higher survival rate than *Leucaena leucocephala.* However, *Leucaena leucocephala* can be relatively used with ameliorative measures on soil especially soil pH. Likewise, *Leucaena leucocephala* contributes to soil fertility enrichment through the symbiotic relationship between the notrobacter and its root nodules for nitrogen fixation into the soil. The researcher, also suggest progressive planting of these species, that is, continual replacement of permanently wilted species.

- Although rainfall distribution was positively skewed and was the only source of water for plant growth, there is need of water supplement by means of irrigation. For instance, Renco Mine is in Natural Region V receiving an average annual rainfall of less than 500mm, which is far less than what is required to sustain early plant growth yearly.

REFERENCES

ARMIGER, B. (1997) Ethics in Nursing Research: Profile, Principles, Perspective. *Nursing Research.* 26 (5). p. 330-333.

ASHBY, W. C. K. P. AND KOST, D. A. (1989) Coal mine reclamation with grasses and legume in southern Illinois. *Journal Soil and Water Conservation,* 44. p. 79-83.

ASHTON, P. J., LOVE, D., MAHACHI, H. AND DIRKS, P. H. G. M. (2001) *An Overview of the Impact of Mining and Mineral Processing Operations on Water Resources and Water Quality in the Zambezi, Limpopo and Olifants Catchments in Southern Africa.* CSIR-Environmentek, Pretoria.

BAKER, A. J. M. AND BROOKS, R. R. (1989) Terrestrial higher plants which hyperaccummulate metal elements: A review of their distribution, ecology, and phytochemistry. *Biorecovery.* 1 (5). p. 81-126.

BAKER, F. A. AND BERTHELOT, D. S. (1999) Long-term Management of Tailings Dams at Decommissioned Mining Properties. *Proceedings of the 23th Annual British Columbia Mine Reclamation Symposium.* Kamloops.

BEAUCHAMP, T. L. AND CHILDRES, J. F. (2001) *Principles of Biomedical Ethics,* 5th Edition. Oxford University Press, Oxford.

BELL, F. G. (1998) *Environmental Geology. Principle and Practice.* Cambridge University Press, UK.

BLESS, C., SMITH, C. H. AND KAGEE, A. (2006) *Fundamentals of Social Research Methods: An African Perspective*, 4th Edition. Juta and Company, Cape Town.

BLIGHT, G. E. (1989) Erosion losses from the surface of gold tailings dams. *Journal of South Africa Institute of Metallurgy.* 89 (1). p. 23-29.

BRACKLEY, J. A. AND ZIUPFU, P. S. E. (1995) *Environmental Impact Assessment for Renco Mine.* Harare: Steffen, Rebertson and Kirsten Consulting Engineers.

BRNICH, M. AND MALLET, L. G. (2003) *Focus on Prevention: Conducting a Hazard Risk Assessment.* NIOSH Publication, Pittsburgh.

CHANBER OF MINES (2015) *Contribution of the mining sector to sustainable development of the Zimbabwean economy.* [Online] Available from: http://www.iac.co.zw/Docs/syllubus/ ChanberofMines.pdf. [Accessed on 30 January 2017].

CAMPBELL, D. T. AND STANLEY, J. C. (1963) *Experimental and Quasi-Experimental Designs for Research on Teaching.* Rand McNally, Chicago.

COOK, J. A. AND JOHNSON, M. S. (2001) *Ecological restoration of land with particular reference to the mining of metals and industrials: A review of theory and practice.* [Online] Available from: http://er.nrc,ca/. [Accessed on 30 March 2017].

CORNISH, R. (2006) *Statistics: An Introduction to Sample Size Calculations.* [Online] Available from: http://www.statstutor.ac.uk/resources/uploaded/sample-size-pdf. [Accessed on 15 January 2017].

CORPS, P. (1990) *Reforestation in the Pacific Islands.* [Online] Available from: http://www.geocities.com/wessaliens/speices/species.htm#leucaena. [Accessed on 15 May 2017].

CRESWELL, J. W. (2007) *Qualitative Inquiry and Research Design: Choosing among Five Approaches*, 2nd Edition. SAGE Publications, Thousand Oaks, California.

CRESWELL, J. W. (2003) *Research Designs: Qualitative, Quantitative, and Mixed Methods Approaches,* 2nd Edition. SAGE Publications, London.

CRESWELL, J. W. (1994) *Research Designs: Qualitative and Quantitative Approaches*. SEGE Publications, Thousand Oaks, California.

DUMBA, T. S. (2013) *Impact of mine pollution composition, diversity and structure of plant and ground-dwelling invertebrate communities around Kombat Mine Tailings dump, Namibia.* Thesis submitted in partial fuifillment of the requirements for the Degree of Master of Science in Biodiversity Management and Research. Humboldt-University, Berlin: University of Namibia.

EDWARDS, R. (1996) Toxic sludge flows through the Andes. *News Scientist,*152. p. 152.

EPA (2006) *The use of soil amendment for remediation, revitalization and reuse.* EPA Publication, Cincinnati.

EPA (2005) *Composite Soil Sampling.* [Online] March 2015 Available from: http://www.epa.sa.gov.au/files/8370_guide_composite.pdf. [Accessed on 30 January 2017].

FORGE, T., BROERSMA, K., NEILSON, G., YU, S. AND RODDAN, B. (2006) *The Impacts of Municipal Biosolids on some Indicators of Soil Health.* [Online] Available from: http://open.library.ubc.ca/clRcle/collections/59367/items/1.0042482. [Accessed on 05 April 2017].

FOUKA, G. AND MANTZOROU, M. (2011) What are the Major Ethical Issues in Conducting Research? *Health Science Journal.* 5 (1). p. 3-14.

FRANKLIN, J. A. AND BUCKLEY, D. S. (2006) Effects of three groundcover treatments on initial oak establishment on a minesite. *Proceedings American Society of Mining and Reclamtion.* p. 848-855.

GARDINER, R. T. (1974) *Mined-Land at Cominco Ltd, Sullivan Operation: Progress Report 1974.* Cominco Ltd, Kimberley.

GARDNER, W. C., BROERSMA, A., NAETH, A., CHANASYK, D. AND JOBSON, A. (2010) Influence of biosolids and fertilizer amendments on physical, chemical and

microbiological properties of copper mine tailings. *Canadian Journal of Soil Science,* 90. p. 571-583.

GARDNER, J. (2001) Rehabilitating mines to meet land use objectives: Bauxite mining in Jarrah forest of Western Australia. *Unasylva,* 207 (8), p. 3-5.

GEORGHION, L. (2015) *Value of Research.* [Online] June 2015 Available from: https://ec.europa.eu/research/innovation-union/pdf/.../georghiou-value_research. [Accessed on 30 January 2017].

GILMAN, E. F. (2014) *Dodonaea viscosa* Varnish Leaf, Hopbush. UF/IFAS Extension, Gainesville.

GLENN, I. D. (1992) *Sampling the Evidence of Extension Program Impact.* University of Florida, Gainesville.

GORMAN, J. (2004) Closure of the Big Springs Tailings Facilities. *Tailings Impoundment Closure Workshop.* Mining Life-Cycle Centre. Mackay School and Earth Sciences and Engineering. University of Nevada. USA, Reno.

GRANGE (1973) Control of dust from mine dumps. *South African Institute of Mining Metallurgy,* 73 (8). p. 67-73.

GRUFFIT, J. J. AND TOY, T. J. (2001) Evolution in revegetation of iron-ore mines in Minas Gerais State, Brazil. *Unasylva,* 207 (52), p. 9-15.

GUOQING, C., MINGJIU, W., ZHENGJIA, L. AND WENGFENG, C. (2017) The Biogeophysical Effects of Revegetation around Mining Areas: A Case Study of Dongsheng Mining Areas in Inner Mangolia. *Sustainability.* 9 (628). [Online] April 2017 Available from: http://www.mdpi.com/journal/sustainability. [Accessed on 30 January 2017].

HORTON, R. AND KEMPE, R. (2001) *Progressive Reclamation Utilizing Biosolids at the Hedley Gold Tailings Project, Hedley, British Columbia, Canada.* In Proceedings of the 25th Annual British Columbia Mine Reclamation Symposium. Campbell River, BC. p. 203-213.

HOX, J. J. AND BOEIJE, H. R. (2005) Data Collection, Primary Vs Secondary. *Encyclopedia of Social Measurement,* 1. p. 593-599.

HSIAO, T. (1973) Plant resonses to water stress. *Annual Review of Plant Physiology,* 24. p. 519-570.

ICREF (2011) *Reclamation and Rehabilitation Plan for Donimalai Iron Ore Mine.* Environmental Management Division, Dehradun.

JAMETON, A. (1984) *Nursing Practice: The Ethical Issues.* Prentice Hall, New Jersey.

JOHNSTONE, M. (2009) *Bioethics*, 5th Edition. Livingstone Elsevier, Churchil.

JUWARKAR, A. A., YADAV, S. K., THAWALE, P. R., KUMAR, P., SINGH, S. K. AND CHAKRABARTI, T. (2009) Development Strategies for Sustainable Ecosystem on Mine Dumps: A case study. *Environmental Monitoring and Assessment,* 157. p. 471-481.

KAPHAIZI, D. (2015) *Vegetation succession on mine tailings dump: A case study of Renco Mine Old Tailings Dump.* Thesis submitted in partial fulfillment of the requirements for the Post-Graduate Diploma in Safety, Health and Environmental Management. Gweru: Midlands State University.

KOSSOFF, D., DUBBIN, W. E., AFREDSSON, M., EDWARDS, S. J., MACKLIN, M. G. AND HUDSON-EDWARDS, K. A. (2014) Mine Tailings Dams: Characteristics, failures, environmental impacts and remediation. *Applied Geochemistry,* 51 (2014). p. 229-245.

LAKE, B. (2000) *Understanding Soil pH*. NSW Agriculture Publication, Yanco.

LARNEY, F. J. AND ANGERS, D. A. (2012) The role of organic amendments in soil reclamation; a review. *Canadian Journal of Soil Science,* 92. p. 19-38.

LEISHMAN, M. AND WESTOBY, M. (1994) The role of seed size in seedling establishment in dry soil conditions-experimental evidence from semi-arid species. *Journal of Ecology,* 82. p. 249-258.

MAC (1998) *A Guide to the Management of Tailings Facilities.* The Mining Association of Canada, Ottawa.

MASHAKADA, A. (2001) Some Guidelienes to mine dump rehabilitation. *FESNEWS.* p. 3-8.

MDA (2017) *Soil Sampling Guidance.* [Online] Available from: http://www.mda.state.mn.us/chemicals/spills/incidentresponse/guidelist/~/media/Files/chemicals/guidancedocs/gd11.ashx. [Accessed on 15 February 2017].

MILLER, G. T. (1992) *Environmental Science Sustaining the Earth*, 4th Edition. Wadsworth Publishing Company, Belmont, California.

MMCZ (2015) *MMCZ 2015 Annual Report.* [Online] Available from: http://www.mmcz.co.zw/media-centre/reports/annual-reports/. [Accessed on 15 February 2017].

MONTGOMERY, D. C. (1997) *Design and Analysis of Experiments,* 4th Edition. John Wiley and Sons, New York.

MOUTON, J. (1996) *Understanding Social Research*. Van Schaik, Pretoria.

MUKHOPADHYAY AND MASTO (2016) Carbon storage in coal mine spoil by Dailbergia sissoo Roxb. *Geoderma.* 284. p. 204-213.

MULIZANE, M., KATSVANGA, C. A. T., NYAKUDYA, I. W. AND MUPANGWA, J. F. (2005) The Growth Performance of Exotic and Indigenous Tree Species in Rehabilitating

Active Gold Mine Tailings Dump at Shamva Mine in Zimbabwe. *Applied Science and Environmental Management.* 9 (2). p. 57-59. [Online] Available from: http://www.bioline.org.br/abstract?id=ja05045&lang=en. [Accessed on 15 February 2017].

NEUMAN, W. L. (2000) *Social Research Methods: Qualitative and Quantitative Approaches*. Allyn and Bacon, Boston.

NHANDARA, E., MUTSVANGWA, L., NHOKO, J. AND SHUMBAYAONDA, W. (1997) *Geography Today Human and Economic*. Mazongororo Paper Convertors, Harare.

NORMAN, D. K. AND RAFORTH, R. L. (1998) Innovations and Trends in Reclamation of Metal-Mine Tailings in Washington. *Washington Geology,* 26 (2). p. 3.

NYAKUDYA, I. W., JIMU, L., KATSVANGA, C. A. T. AND DAFANA, M. (2011) Comparative analysis of the early growth performance of indigenous Acacia species in revegetating Trojan Nickel Mine Tailings in Zimbabwe. *African Journal of Environmental Science and Technology.* [Online] 5 (3). p. 218-227. Available from: http://www.academicjournals.org/AJEST. [Accessed on 30 March 2017].

OEHLERT, G. W. (2010) *A First Course in Design and Analysis of Experiments.* [Online] Available from: http://users.stat.umn.edu/~gary/book/fcdae.pdf. [Accessed on 30 January 2017].

PANDEY, P. AND PANDEY, M. M. (2015) *Research Methodology: Tools and Techniques.* Bridge Centre, Romania.

PEPPER, L. I., BENGSON, P., RAO, R. AND JOSEPHSON, K. L. (2003) *Revegetation of Mine Tailings Through the use of Biosolid Amendment.* Proceedings of the American Society of Mining and Reclamation and the 9th Billings Land Reclamation Symposium, Billings MT, June 3 – 6, 2003, ASMR, Lexington. p. 961-974.

PEARMAN, G. (2002) *Dodonaea viscosa Jacq*. In: Oyen, L.P.A. & Lemmens, R.H.M.J. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands

PHILLIPS, D. C. AND BURBULES, N. C. (2000) *Postpositivism and Educational Research.* Rowman and Littlefield, Lanham.

PRZECZEK, J. (2004) *A review of reclamation research program at Teck Cominco's Sullivan Mine at Kimberley Operations.* Proceedings of the 2004 BC Mine Reclamation Syposium, BC Technical and Research Committee on Reclamation, June 23-24, 2004, Cranbrook, Canada. p. 7.

QUINN, G. P. AND KEOUGH, M. J. (2012) *Experimental Designs and Data Analysis for Biologits.* Cambridge University Press, New York.

RANI, M., PIPPALLA, R. S. AND MOHAN, K. (2009) *Dodonaea viscosa* - An Overview. *JPRHC,* 1(1). p. 97-112.

RANJAN, V. SEN, P., KUMAR, D. AND SARSAWT, A. (2015) A review on dump slope stabilization by revegetation with reference to indigenous plant. *Ecological Processes,* 4 (14). p. 1-11. [Online] Available from: https://link.springer.com/article/10.1186/s13717-015-0041-1. [Accessed on 15 June 2017].

RIOZIM (2016) *Annual Report 2016.* [Online] Available from: http://www.riozim.co.zw/?page_id=74. [Accessed on 15 June 2017].

RIZZA, J., FRANKLIN, J. AND BUCKLEY, D. (2007) The influence of different ground cover treatments in the and survival of tree seedlings on remined sites in Eastern Tennessee. *Proceedings America Society of Mining and Reclamation.* p. 633-677.

RORISON, I. H. (1977) The effect of extreme soil acidity on the nutrient uptake and physiology of plants. *International Institute for Land Reclamation and Improvement,* 1(6). p. 233-251.

RUPPEL, O. C. AND RUPPEL-SCHLICHTING, K. (2011) *Environmental Law and Policy in Namibia.* Orumbonde Press and Welwitschia, Windhoek.

SAS (2005) *Concept of Experimental Design*. [Online] Available from: http://support.sas.com/resources/papers/sissigma1.pdf. [Accessed on 20 January 2017].

SCHOENBRUNN, F. AND LAROS, T. J. (1997) *Dry tailings disposal using Hi-Density thickening.* Proceedings of Tailings and Mine Waste '97. Balkema, Rotterdam. p. 357-363.

SCHWARTZKOPF, C. (1972) *Potassium, Calcium, Magnesium – How they Relate to Plant Growth.*

SEKHAR, D. AND JAKHU, M. R. (2005) Primary Vegetation Growth on an Old Tailings Dam at Zawar Mine. *Environmental Geochemistry and Health,* 5 (6). p. 128-132.

SIRDC (2017) Soil Fertility Test for Renco Mine. *Test Report No. SSFR/ J0089.* p. 1-2

SINGH, A. (2015) Growth Performance of *Leucaena Leucocephala* on a coal mine. *Indian Journal of Fundamental and Applied Science,* 5 (1). p. 169-171.

SINGH, A. S. (2014) Sampling Techniques and Determination of Sample Size in Applied Statistics Research: An Overview. *International Journal of Economics, Commerce and Management.* 2 (11). p. 1-22.

SINGH, J. S. AND JHA, A. K. (1993) *Restoration of Degraded Land: Concepts and Strategies.* Rastogi Publications, Meerut.

SINGH, A. N., RAGHUBANSHI, A. S. AND SINGH, J. S. (2004) Impact of native tree plantations on mine spoils in a dry tropical environment. *Forest Ecological Management,* 187. p. 49-60.

SHEORAN, V. AND POONIA, P. (2010) Soil Remediation of Abandoned Mine Land by Revegetation: A Review. *International Journal of Soil, Sediment and Water.* 3 (2). [Online] Available from: http://scholarworks.umass.edu/intljssw/vol13/iss2/13. [Accessed on 30 January 2017].

SHU, W. S., XIA, H. P., ZHANG, Z. Q. AND WONG, M. H. (2002) Use of vertiver and other three grasses for revegetation of Pb/Zn mine tailings: field experiment. *International Journal on Phytoremediation,* 4 (1). p. 47-57.

SNEDECOR, G. W. AND COCHRAN, W. G. (1989) *Statistical Methods,* 8th edition. Iowa Sate College Press, Ames.

SONI, P. (2009) Species Selection for Revegetation and Consolidation of Uranium Tailings at Jaduguda in Jharkhaand in India. *An International Journal of Environmental Science,* 3 (1) (2). p. 19-25.

SPECTOR, P. E. (1981) *Research Designs.* SAGE Publications, Beverly Hills.

STANLEY, J., BUXTON, R., ALSPACH, P., MORGAN, C., MARTINDALE, D. AND SAROSA, W. (2000) Developing Optimum Strategy for Rehabilitating Overburden Stockpile at the Grasberg Mine. *Proceedings of the 11th International Peat Congress.* Quebec, 96-11 August 2000: Commission V. p. 806-814.

STRONG, W. L. (1998) *Vegetation Survey of Reclaimed Lands within the Luscar Sterco Coal Valley Mine.* Ecological Land Surveys Ltd, Alberta.

SWANN, K. (2007) *Mine Waste Revegetation.* [Online] Available from: http://www.otago.ac.nz/geology/. [Accessed on 20 April 2017].

THOMPSON, C. B. AND PANACEK, E. A. (2006) Research Study Designs: Exiperimental and Quasi-experimental. *Air Medical Journal.* 26 (6). p. 242-246.

TOUCEDA-GONZALEZ, M., ALVAREZ-LOPEZ, V., PRIETO-FERNANDEZ, A., RODRIGUEZ-GARRIDO, B., TRASAR-CEPEDA,C., MENCH, M.,

PUSCHENREITER, M., QUINTELA-SABARIS, C., MACIAS-GARCIA, F. AND KIDD, P.. (2017) Aided phytostabilisation reduces metal toxicity, improves soil fertility and enhances microbial activity in Cu-rich mine tailings. *Journal for Environmental Management.* 186. p. 301-313.

TROUNG, P. N. V. (1999) *Vertiver grass technology for mine tailings rehabilitation.* Asia-Pacific Conference on Ground and Water Bio-engineering. Unpublished Report.

UCHIDA, R. (2000) Essential Nutrients for Plant Growth: Nutrient Functions and Deficiency Symptoms. In Silva, J. A. and Uchida, R. (eds). *Plant Nutrient Management in Hawaii's Soils.* University of Hawaii, Monao.

UNDP (2015) *Sustainable Development Goals.* [Online] Available from: http://www.undp.org›SDG-_Booklet_Web_En. [Accessed on 20 March 2017].

UNIVERSITY OF SOUTHERN CALIFORNIA LIBRARIES (2016) *Organizing Your Social Science Research Paper: Types of Research Designs*. [Online] Available from: http://libguides.usc.edu/content.php?pid=83009&sid=818072. [Accessed on 20 January 2017].

WATERHOUSE, B. R., BOYER, S., ADAIR, K. L. AND WRATTEN, S. D. (2014) Using municipal biosolids in ecological restoration: what is good for plants and soil may not be good for endemic earthworms. *Ecological Engineering,* 70. p. 414-421.

WIJESEKARA, H., BOLAN, N. S., KUMARATHILAKA, P., GEEKIYANAGE, N., KUNHIKRISHNAN, A., SESHADRI, B., SAINT, C., SURAPANENI, A AND VITHANAGE, M. (2016) Biosolids enhance mine rehabilitation and revegetation. *Environmental Materials and Waste,* 138. p. 45-64.

WELMAN, J. C., KRUGER, F., MITCHELL, B. AND HUYSAMEN, G. K. (2005) *Research Methodology*, 3rd Edition. Oxford University Press.

WILLIAMS, C. (2007) Research Methods. *Journal of Business and Economic Research.* 5 (3). [Online] Available from:

https://www.cluteinstitute.com/ojs/index.php/JBER/article/viewFile/2532/2578.
[Accessed on 15 March 2017].

WILLIAMS, J. L. AND CRONE, E. E. (2006) the impact of invasive grasses on the population growth of Anemone patens, a long-lived native forb. *Ecology,* 87 (12). p. 3200-3208.

WRIGHT, M. A., WHITE, M. A., BASKER, S., BURTON. P., DAVIDSON, R., FALVEY, S., GALLEGOS, T., HARDEN, R., HUNT, G., JENSEN, D., KRUEGER, R., MALIN, L., ROL, D., SMITH, J., SUFLITA, M. AND WYATT, K. (2004) The Practical Guide to Reclamation. *New Phytologist.* 154 (1). p. 29-43.

YAMANE, T. (1967) *Statistics: An Introductory Analysis,* 2nd Edition. Harper and Row, New York.

YANG, B., SHU, W. S., YE, Z. H., LAN, C. Y. AND WONG, M. H. (2003) Growth and metal accumulation in vertiver and two *Sesbania* species on lead/zinc mine tailings. *Chemosphere,* 52(9). p. 1593-1600. [Online] Available from: https://www.ncbi.nlm.nih.gov/pubmed/12867192 [Accessed on 15 March 2017].

ZANUZZI, A., AROCENA, J. M., VAN-MOURIK, J. M. AND FAZ CANO, A. (2009) Amendments with organic and industrial waste stimulate soil formation in mine tailings as revealed by micromorphology. *Geoderma,* 154. p. 69-75.

ZELLNER, C. (2003) The economic effects of basic research: evidence for embodied knowledge transfer via scientists' migration. *Research Policy.* 32(10). p. 1881-1895.

ZHANG, Z. Q., SHU, W. S., LAN, C. Y. AND WONG, M. H. (2001) Soil seed bank as an input of seed sources in vegetation of lead/zinc mine tailings. *Restoration Ecology,* 9(4). p. 1-8.

ZIMBABWE. *Constitution of Zimbabwe* Amendment (No. 20) Act. (2013) Harare: Government Printers.

ZIMBABWE. *Environmental Management Act Chapter 20:27.* (2003) Harare: Government Printers.

ZIMBABWE. *Environmental Management (Effluent and Solid Waste Disposal) Regulations. S.I. 6.* (2007) Harare: Government Printers.

ZIMBABWE. *Mines and Minerals Act Chapter 21:05.* (1961) Harare: Government Printers.

ZIMBABWE. *Mining Management (Health and Safety) Regulations. S.I. 109.* (1990) Harare: Government Printers.

ZIMBABWE (2013) *Zimbabwe Agenda for Sustainable Socio-economic Transformation.* [Online] Available from: http://www.herald.co.zw/wp-content/uploads/2014/01/Zim-Asset.pdf. [Accessed on 20 March 2017].

APPENDICES

APPENDIX A1: Research Letter Approval

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

TO WHOM IT MAY CONCERN

REQUEST TO CARRY OUT A RESEARCH STUDY IN YOUR ORGANISATION

This letter serves to confirm that DAVISON KAPHAIZI.......Registration Number.....R104736R........................... is a student at the Midlands State University doing Master of Science in Safety, Health and Environmental Management. May you please assist him/her in any way possible to carry out his/her research.

We thank you in advance for any assistance you will offer.

Dr T. Marambanyika
CHAIRPERSON
GEOGRAPHY AND ENVIRONMENTAL STUDIES

APPENDIX B1: Sample Advice from Researcher to SIRDC

No. 1 Orchid Close
Renco Mine

SIRDC
P. O. Box 6640
1574 Alpes Road/Technology Drive
Hatcliff
Harare

Dear Sir,

RE: SAMPLE ADIVICE FOR FULL SOIL FERTILITY ANALYSIS

SWren.17 and NSren.17 are two composite soil samples extracted from subsamples obtained from two soil types found in the surrounding area of Renco Mine tailings dump. The two soil types have been used for planting trees at Renco Mine tailings dump. May you conduct a Full Soil Fertility Analysis on both samples. Generally, I want to get recommendations on the continued use of these soil types in revegetation of mine tailings dumps.

Find herewith proof of payment made for the analysis.

Your support in this regard is greatly commended.

Davison Kaphaizi
+263773306659
+263719306659

APPENDIX B2: SIRDC Soil Fertility Report Form

SIRDC

SCIENTIFIC & INDUSTRIAL RESEARCH & DEVELOPMENT CENTRE

Visiting Address:
P O Box 6640
1574 Alpes Road/Technology Drive Harare
Hatcliffe,
Harare
Zimbabwe

Telephone: +263-4-860320-9
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Direct   +263-4-860357
Fax: +263-4-860350-1
E-mail: fbti@sirdc.ac.zw

Analytical Services

Test Report No. SSFR/ J0089 (1-2)

Page 1 of 2

SOIL FERTILITY TEST REPORT FORM

Sample details:	Customer details:
Sample Laboratory reference number: J0089(1-2)	Customer name: Mr. Kaphaizi
Sample description: Soil Samples	Customer contact person: Mr. Kaphaizi
Date sample received: 20/09/2017	Customer contacts address: Mr. Kaphaizi, Renco Mine
Date sample tested: 20/09/2017	

Table 2 : Test results

Sample number	Customer ref	pH 0.01M CaCl$_2$	Potassium (meq/100g)NH$_4$Cl Extractable	Calcium (meq/100g) NH$_4$Cl Extractable	Magnesium (meq/100g) NH$_4$Cl Extractable	Phosphorous (ppm) Resin Extractable	Initial nitrogen 1M KCl Extractable
J0089/01	SWren 17	3.85	0.01	4.10	0.16	80.02	35.03
J0089/02	NSren 17	4.28	0.01	5.08	0.19	7.06	24.52

Block	Elev. Coord. X	Elev. Coord. Y	Dec Initial HT (cm)	Dec Initial RD (cm)	Dec Actual HT (cm)	Dec Actual RD (cm)	Dec Increm HT (cm)	Dec Increm RD (cm)	Jan Actual HT (cm)	Jan Actual RD (cm)	Jan Increm HT (cm)	Jan Increm RD (cm)	Feb Actual HT (cm)	Feb Actual RD (cm)	Feb Increm HT (cm)	Feb Increm RD (cm)	Mar Actual HT (cm)	Mar Actual RD (cm)	Mar Increm HT (cm)	Mar Increm RD (cm)	Apr Actual HT (cm)	Apr Actual RD (cm)	Apr Increm HT (cm)	Apr Increm RD (cm)	May Actual HT (cm)	May Actual RD (cm)	May Increm HT (cm)	May Increm RD (cm)	Jun Actual HT (cm)	Jun Actual RD (cm)	Jun Increm HT (cm)	Jun Increm RD (cm)	Jul Actual HT (cm)	Jul Actual RD (cm)	Jul Increm HT (cm)	Jul Increm RD (cm)	Aug Actual HT (cm)	Aug Actual RD (cm)	Aug Increm HT (cm)	Aug Increm RD (cm)	Total Averages HT (cm)	Total Averages RD (cm)
661	308231	7717777	62.3	0.5	62.3	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308202	7717769	72.1	0.8	73.4	0.89	1.3	0.09	93.1	0.93	19.7	0.04	99	0.94	5.9	0.01	107	0.95	8	0.01	115	0.96	8.1	0.01	121	0	6.1	0	128	0.97	6.8	0.01	135.5	0.99	7.5	0.02	142	1	6.8	0.01	6.8	0.01
657	308133	7717729	30.5	0.3	32	0.3	1.5	0	33.6	0.3	1.6	0	38	0.34	4.4	0.04	42.7	0.36	4.7	0.02	50.1	0.44	7.4	0.08	55.5	0.48	5.4	0.04	59.6	0.51	4.1	0.03	63.7	0.55	4.1	0.04	65.8	0.58	2.1	0.03	9.3	0.03
657	302745	7717794	60	0.68	61.3	0.69	1.3	0.01	64	0.9	2.7	0.21	70.3	0.97	6.3	0.07	76.3	1.04	6	0.07	84.3	1.1	8	0.06	88.3	1.14	4	0.04	94	1.16	5.7	0.02	101.4	1.18	7.4	0.02	111	1.21	9.3	0.03	9.3	0.03
657	308210	7717767	63	0.62	64.1	0.68	1.1	0.06	67	0.9	2.9	0.01	71.5	0.73	4.5	0.04	76.3	0.77	4.8	0.05	81.7	0.82	5.4	0.05	86.8	0.84	5.1	0.02	90.4	0.87	3.6	0.03	93	0.89	2.6	0.02	97.5	0.91	4.5	0.02	4.5	0.02
656	308170	7717747	33.2	0.54	35.2	0.54	1.2	0.08	28.5	0.49	0	0	32.5	4	0	0	36.5	0.55	0	0	43.1	0.62	6.6	0.07	48	0.68	4.9	0.06	51.1	0.71	3.1	0.03	54.1	0.73	3	0.02	57.1	0.77	3	0.04	3	0.04
657	308210	7717767	63	0.62	64.1	0.68	1.1	0.06	67	0.69	2.7	0.01	71.5	0.73	4.5	0.04	76.3	0.77	4.8	0.05	81.7	0.82	5.4	0.05	86.8	0.84	5.1	0.02	90.4	0.87	3.6	0.03	93	0.89	7.4	0.02	97.5	0.91	4.5	0.02	4.5	0.02
656	308060	7717791	27.3	0.4	28.5	0.48	1.2	0.08	28.5	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
655	308223	7717771	43.6	0.52	50	0.53	6.4	0.01	50	0.6	0	0.07	56.6	0.69	6.6	0.09	60.3	0.75	3.7	0.06	69	0.82	8.7	0.07	72.3	0.87	3.3	0.05	75.4	0.89	3.1	0.02	77.7	0.92	2.3	0.03	79.5	0.95	1.8	0.03	1.8	0.03
657	308168	7717746	35	0.4	43	0.45	8	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
656	308090	7717703	43	0.4	51.5	0.41	8.5	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
656	308276	7717795	58.7	0.76	64	0.93	5.3	0.17	78.5	0.95	14.5	0.02	86.5	1.05	1.6	0.08	86.5	1.05	6.4	0.08	91.2	1.11	4.7	0.06	94.5	1.15	3.3	0.04	96.2	1.17	1.7	0.02	99.4	1.2	3.2	0.03	104	1.22	4.2	0.02	4.2	0.02
656	308090	7717703	43	0.4	51.5	0.41	8.5	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308040	7717680	18.1	0.3	19	0.3	0.9	0	76.3	0.22	0	0.04	79.3	0.6	0	0.08	82.1	0.66	2.8	0.06	86.1	0.7	4	0.04	90.3	0.76	4.2	0.06	95.2	0.81	4.9	0.05	99.8	0.85	4.6	0.04	104	0.89	4.2	0.04	4.2	0.04
657	308175	7717747	75	0.45	75.4	0.48	0.4	0.03	78.5	0.95	0.9	0.04	80.1	0.97	1.6	0.02	86.5	1.05	6.4	0.08	91.2	1.11	4.7	0.06	94.5	1.15	3.3	0.04	96.2	1.17	1.7	0.02	99.4	1.2	3.2	0.03	104	1.22	4.2	0.02	4.2	0.02
655	308287	7717792	62	0.6	62.4	0.6	0.4	0	70	0	7.6	0	75.3	0.73	5.3	0.13	79.5	0.79	4.2	0.06	93.6	0.86	14.1	0.07	96.5	0.91	2.9	0.05	101	0.99	4.5	0.08	106.4	1.08	5.4	0.09	110	1.16	3.1	0.08	3.1	0.08
657	308225	7717765	36.6	0.71	38.9	0.72	2.3	0.01	40	0.77	1.1	0.05	45.6	0.9	4.7	0.02	45.6	0.8	4.7	0.01	52.1	0.88	6.5	0.08	56.1	0.92	4	0.04	60.2	0.99	4.1	0.07	64.5	1.11	4.3	0.12	67.4	1.18	2.9	0.07	2.9	0.07
654	308183	7717745	58.2	0.5	58.5	0.8	0.3	0.3	60.8	0.81	2.3	0.01	63.4	0.84	2.6	0.03	68.2	0.87	4.8	0.03	75.3	0.92	7.1	0.05	81.1	0.98	5.8	0.06	85.3	1.06	4.2	0.08	89.3	1.15	4	0.09	93.8	1.2	4.5	0.05	4.5	0.05
656	308109	7717764	30.5	0.3	31.6	0.3	1.1	0	33.6	0.3	2	0	38.1	0.48	6	0.04	48	0.54	4	0.03	55.5	0.65	7.5	0.11	60.8	0.7	5.3	0.05	63.5	0.74	2.7	0.04	67.8	0.79	4.3	0.05	71	0.83	3.2	0.04	3.2	0.04
635	308077	7717695	31.5	0.34	32.1	0.44	0.6	0.1	38.1	0.48	6	0.04	44	0.51	5.9	0.03	48	0.54	4	0.03	55.5	0.65	7.5	0.11	60.8	0.7	5.3	0.05	63.5	0.74	2.7	0.04	67.8	0.79	4.3	0.05	71	0.83	3.2	0.04	3.2	0.04
Average							2.26	0.06			3.32	0.03			2.83	0.03			3.23	0.03			4.89	0.04			3.02	0.03			2.69	0.03			2.93	0.03			2.76	0.03	3.10	0.03
Survival Rates				100			66.67				66.67				66.67				66.67				66.67				66.67				66.67				66.67				66.67		66.67	

Key

HT:	Height
RD:	Root Collar Diameter
Increment:	Increments
Elev.:	Elevation
[red] :	Wilted

APPENDIX C2: Raw Data for *Dodonaea viscosa* planted as control on natural soil with grass-covered surface

Block	Elev. Coordinates		December Initial		December Actual		December Increment		January Actual		January Increment		February Actual		February Increment		March Actual		March Increment		April Actual		April Increment		May Actual		May Increment		June Actual		June Increment		July Actual		July Increment		August Actual		August Increment		Total Averages	
	X	Y	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)
1 (Grass cover) 656	308270	771797	60.7	0.65	61.6	0.81	0.9	0.16	62.5	0.81	0.9	0	66	0.87	3.5	0.06	70.4	0.9	4.4	0.03	75.3	0.98	4.9	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308245	771760	48.8	0.6	50.4	0.6	1.6	0	68.4	0.65	18	0	74.4	0.68	6	0.03	81.7	0.74	7.3	0.06	0	0	0	0	89.1	0.68	7.5	0.04	93.2	0.73	4.1	0.05	95.8	0.79	2.6	0.06	97.9	0.86	2.1	0.07
655	308167	771744	60.1	0.7	62.7	0.7	2.6	0	64.8	0.7	2.1	0	70.4	0.72	5.6	0.02	76	0.75	5.6	0.03	75.8	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
658	308077	771755	34.2	0.52	36.5	0.58	2.3	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308226	771754	60	0.56	62.7	0.66	2.7	0.1	65	0.72	2.3	0.06	69.1	0.79	4.1	0.07	73.8	0.85	4.7	0.06	77.7	0.91	3.9	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
656	308181	771734	64.7	0.63	64.9	0.73	0.2	0.1	66.1	0.81	1.2	0.08	69.9	0.9	3.8	0.09	77	0.95	7.1	0.05	81.4	1.01	4.4	0.06	86.2	1.06	4.8	0.05	91.1	1.1	4.9	0.04	95.6	1.16	4.5	0.06	98	1.19	2.4	0.03
654	308134	771752	28.7	0.3	28.8	0.31	0.1	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
657	308270	771791	40.6	0.49	40.7	0.49	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
657	308180	771751	68.1	0.5	68.8	0.53	0.7	0.03	68.9	0.53	0.1	0	71.1	0.59	2.2	0.06	75.3	0.64	4.2	0.05	81.6	0.64	6.3	0	89.1	0.68	7.5	0.04	0	0	0	0	0	0	0	0	0	0	0	0
658	308146	771753	30.8	0.6	37.4	0.6	6.6	0	38.1	0.62	0.7	0	44.5	0.68	6.4	0.06	48.8	0.76	4.3	0.08	55	0.82	6.2	0.06	59.9	0.85	4.9	0.03	62.8	0.88	2.9	0.03	66.2	0.91	3.4	0.03	70	0.93	3.8	0.02
658	308078	771736	37	0.5	37.3	0.5	0.3	0	39.3	0.7	2	0.2	43.2	0.76	3.9	0.06	45.1	0.8	1.9	0.04	49.5	0.85	4.4	0.05	53.4	0.89	3.9	0.04	55.8	0.91	2.4	0.02	59	0.93	3.2	0.02	62.7	0.96	3.7	0.03
656	308221	771768	31.7	0.5	33	0.58	1.3	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
657	308059	771791	49.5	0.78	50.1	0.78	0.6	0	50.1	0.8	0	0.02	53.5	0.94	3.4	0.04	58.9	0.86	5.4	0.02	63.1	0.92	4.2	0.06	69.1	0.95	6	0.03	72	0.97	2.9	0.02	76.1	0.99	4.1	0.02	80.8	1.02	4.7	0.03
659	308043	771765	18.6	0.26	19	0.28	0.4	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308272	771799	57.2	0.8	72.5	0.83	15.3	0.03	74.6	0.83	2.1	0	78.8	0.86	4.2	0.03	83.4	0.89	4.6	0.03	88.8	0.94	5.4	0.05	94.9	0.99	6.1	0.05	97.6	1.02	2.7	0.03	100	1.07	2.4	0.05	103	1.11	2.8	0.04
656	308180	771733	67.5	0.9	69	0.9	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
654	308167	771759	37	0.62	56	0.7			58.5	0.71	2.5	0.01	64.3	0.76	5.8	0.05	68.5	0.81	4.2	0.05	75.8	0.9	7.3	0.09	80	0.95	4.2	0.05	84.8	1	4.8	0.05	89.1	1.05	4.3	0.05	92.8	1.11	3.7	0.06
655	308161	771733	55	0.64	56	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average							2.07	0.03			1.77	0.02			2.72	0.03			2.98	0.03			2.61	0.03			2.08	0.02			1.37	0.01			1.36	0.02			2.03	0.02
Survival Rates			94.44						61.11				61.11				61.11				50.00				38.89				38.89				38.89				38.89			

Note: In the table below, red "0" cells denote Wilted plants (see Key).

Block	X	Y	Init HT	Init RD	Dec Act HT	Dec Act RD	Dec Inc HT	Dec Inc RD	Jan Act HT	Jan Act RD	Jan Inc HT	Jan Inc RD	Feb Act HT	Feb Act RD	Feb Inc HT	Feb Inc RD	Mar Act HT	Mar Act RD	Mar Inc HT	Mar Inc RD	Apr Act HT	Apr Act RD	Apr Inc HT	Apr Inc RD	May Act HT	May Act RD	May Inc HT	May Inc RD	Jun Act HT	Jun Act RD	Jun Inc HT	Jun Inc RD	Jul Act HT	Jul Act RD	Jul Inc HT	Jul Inc RD	Aug Act HT	Aug Act RD	Aug Inc HT	Aug Inc RD	Tot HT	Tot RD
658	308234	7717781	21.6	0.69	24.2	0.71	2.6	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308154	7717725	14.4	0.51	14.5	0.55	0.1	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
658	308109	7717712	22	0.7	22	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308242	7717753	23.6	0.71	23.6	0.73	0	0.02	33.4	0.84	9.8	0.11	35	0.9	1.6	0.06	39.1	0.95	4.1	0.05	42.5	1.02	3.4	0.07	45.5	1.06	3	0.04	48.2	1.09	2.7	0.03	50	1.11	1.8	0.02	52	1.13	2	0.02		
657	308199	7717762	16.5	0.7	17.5	0.7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
657	308118	7717725	50.1	1.1	50.1	1.1	0	0	57.5	1.3	7.4	0.2	61.6	1.39	4.1	0.09	66.8	1.45	5.2	0.06	71.1	1.49	4.3	0.04	75.5	1.51	4.4	0.02	0	0	0	0	0	0	0	0	0	0	0	0		
659	308267	7717790	54.9	1.2	54.9	1.2	0	0	56	1.2	1.1	0	57.1	1.23	1.1	0.03	62	1.25	4.9	0.02	70.6	1.32	8.6	0.07	74	1.36	3.4	0.04	76.8	1.38	2.8	0.02	79.8	1.4	3	0.02	81.7	1.42	1.9	0.02		
658	308225	7717772	10.1	0.6	10.1	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308145	7717732	33.7	0.9	33.7	0.9	0	0	35.8	0.9	2.1	0	35.9	0.92	0.1	0.02	38.5	0.96	2.6	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
654	308083	7717705	25.7	0.64	25.7	0.65	0	0.01	25.7	0.65	0	0	25.8	0.68	0.1	0.03	29.1	0.68	3.3	0	32.1	0.68	3	0	35.8	0.69	3.7	0.01	37.7	0.71	1.9	0.02	38.9	0.73	1.2	0.02	41.7	0.76	2.8	0.03		
658	308225	7717764	23	0.7	25.1	0.79	2.1	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
657	308065	7717692	26.1	0.94	27.3	0.99	1.2	0.05	28.1	0.99	0.8	0	29.1	1.1	1	0.11	34	1.13	4.9	0.03	39	1.19	5	0.06	41.1	1.25	2.1	0.06	43.7	1.27	2.6	0.02	45.8	1.3	2.1	0.03	47	1.32	1.2	0.02		
658	308401	7717675	13.1	0.56	15.1	0.56	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
658	308237	7717770	38.3	0.8	38.3	0.8	0	0	38.3	0.8	0	0	41.1	0.84	2.8	0.04	45.8	0.9	4.7	0.06	48	0.95	2.2	0.05	52	0.99	4	0.04	54.1	1.03	2.1	0.04	57.6	1.05	3.5	0.02	59	1.07	1.4	0.02		
653	308156	7717734	64.6	1.54	64.6	1.6	0	0.06	67.1	1.66	2.5	0.06	70.1	1.7	3	0.04	75.1	1.73	5	0.03	79.7	1.86	4.6	0.13	81.1	1.9	1.4	0.04	83.2	1.93	2.1	0.03	85.7	1.95	2.5	0.02	88	1.97	2.3	0.02		
655	308106	7717705	28.1	1.11	28.1	1.11	0	0	30	1.11	1.9	0	31.3	1.13	1.3	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
653	308104	7717706	28.1	1.16	28.1	1.18	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	308104	7717706	55.1	1.16	56.1	1.18	1	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	305698	7717702	42.5	0.94	44.5	0.94	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average							0.67	0.02			1.42	0.02			0.84	0.02			1.93	0.02			1.73	0.02			1.22	0.01			0.79	0.01			0.78	0.01			0.64	0.01	1.11	0.02
Survival Rates					100				55.56				55.56				38.89				38.89				38.89				38.89				33.33				33.33				33.33	

Key

HT:	Height	
RD:	Root Collar Diameter	
Increment:	Increments	
Elev.:	Elevation	
[red] 0 :	Wilted	

APPENDIX C4: Raw Data for *Leucaena leucocephala* planted on biosolids with grass-covered surface

Block	Elev. Coordinates X	Y	December Initial HT (cm)	RD (cm)	December Actual HT (cm)	RD (cm)	December Increment HT (cm)	RD (cm)	January Actual HT (cm)	RD (cm)	January Increment HT (cm)	RD (cm)	February Actual HT (cm)	RD (cm)	February Increment HT (cm)	RD (cm)	March Actual HT (cm)	RD (cm)	March Increment HT (cm)	RD (cm)	April Actual HT (cm)	RD (cm)	April Increment HT (cm)	RD (cm)	May Actual HT (cm)	RD (cm)	May Increment HT (cm)	RD (cm)	June Actual HT (cm)	RD (cm)	June Increment HT (cm)	RD (cm)	July Actual HT (cm)	RD (cm)	July Increment HT (cm)	RD (cm)	August Actual HT (cm)	RD (cm)	August Increment HT (cm)	RD (cm)	Total Averages HT (cm)	RD (cm)
1 (Grass cover)																																											
661	308255	7711789	26.1	0.7	26.1	0.7	0	0	27.1	0.7	1	0	30.5	0.73	3.4	0.03					42.5	1.4	4.4	0.1	46	1.44	3.5	0.04	49.9	1.49	3.9	0.05	56.1	1.53	6.2	0.04	60	1.59	3.9	0.06	61.11	0.03
656	308166	7711763	27.5	0.9	34.4	0.99	6.9	0.09	48.1	1.15	13.7	0.16	51.5	1.21	3.4	0.06	57.5	1.27	6	0.06	63	1.33	5.5	0.06	68.1	1.39	5.1	0.06	71.2	1.44	3.1	0.05	75.3	1.48	4.1	0.04	79.9	1.52	4.6	0.04		
658	308138	7711730	26.4	0.7	26.4	0.89	0	0.19																																		
657	308270	7711795	26.2	1.16	29	1.2	2.8	0.04	33	1.23	4	0.03	35	1.26	2	0.03	38.1	1.3	3.1	0.04	42.5	1.4	4.4	0.1	46	1.44	3.5	0.04	49.9	1.49	3.9	0.05	56.1	1.53	6.2	0.04	60	1.59	3.9	0.06		
659	308229	7711775	22.8	1	28.1	1	5.3																																			
660	308150	7711737	36	0.77	36	0.79	0	0.02																																		
654	308097	7711712	22.3	0.67	24.7	0.7	2.4	0.03	27.4	0.76	2.7	0.06	29.1	0.81	1.7	0.05	35	0.86	5.9	0.05	40.5	0.92	5.5	0.06	45.5	0.96	5	0.04	49.7	1.1	4.2	0.14	55	1.18	5.3	0.08	59.7	1.21	4.7	0.03		
660	308243	7711780	17.4	0.44	17.4	0.48	0	0.04																																		
657	308002	7711767	14.5	0.8	14.5	0.83	0	0.03	14.5	0.92	0	0.09	16.5	0.95	2	0.03	20.1	0.98	3.6	0.05	26.7	1.04	6.6	0.06	30.2	1.08	3.5	0.04	34.3	1.1	4.1	0.02	38.8	1.12	4.5	0.05	42.1	1.14	3.3	0.02		
658	308102	7711707	67.8	1.2	67.8	1.2	0		67.8	1.2	0		69	1.26	1.2	0.06	71.5	1.3	2.5	0.04	76.4	1.36	4.9	0.06	80.7	1.4	4.3	0.04	84.3	1.44	3.6	0.04	87.9	1.49	3.6	0.05	90.8	1.52	2.9	0.03		
658	308256	7711775	33.5	0.7	38	0.75	4.5	0.05	42.5	0.82	4.5	0.07	46.5	0.9	4	0.08	50.5	0.95	4	0.05	56.1	1.01	5.6	0.06	60.7	1.06	4.6	0.05	64.1	1.09	3.4	0.03	67.9	1.13	3.8	0.04	70.1	1.19	2.2	0.06		
655	308002	7711744	50.5	0.51	52.5	0.53	2	0.02	52.5	0.52	0	-0	55.6	0.53	3.1	0.01	60.5	0.59	4.9	0.06	65	0.65	4.5	0.06	69.1	0.68	4.1	0.03	73.8	0.7	4.7	0.02	77.8	0.74	4	0.04	80.7	0.79	2.9	0.05		
657	308060	7711769	26.1	0.86	27	0.86	0.9		28.1	0.86	1.1		30.2	0.9	2.1	0.04	35.1	0.95	4.9	0.05	41	1.01	5.9	0.06	45.5	1.05	4.5	0.04	49.7	1.08	4.2	0.03	54.8	1.14	5.1	0.06	59.9	1.16	5.1	0.02		
655	308257	7711781	23.6	0.6	23.6	0.7	0	0.1	24.1	0.7	0.5	0	28	0.71	3.9	0.01	31.9	0.75	3.9	0.05	36.6	0.79	4.7	0.04	40.7	0.82	4.1	0.03	43.8	0.85	3.1	0.03	47.9	0.88	4.1	0.03	50.5	0.9	2.6	0.02		
654	308201	7711761	12.6	0.7	12.6	0.89	0	0.19	12.6	0.92	0	0.03	15.9	0.98	3.3	0.06	20	1	4.1	0.02	25	1.06	5	0.06	27.3	1.1	2.3	0.04	29.9	1.16	2.6	0.06	35.4	1.2	5.5	0.04	38.9	1.24	3.5	0.04		
660	308060	7711781	26.1	0.86	23.6	0.7	0	0.1																																		
654	308186	7717699	29.1	1	30.1	1	1	0	33.2	1	3	0	37.1	1.17	3.9	0.17	40.6	1.2	3.5	0.03	45.1	1.24	4.5	0.04	49.1	1.26	4	0.02	52	1.28	2.9	0.02	56.7	1.3	4.7	0.02	60.7	1.32	4	0.02		
652	308186	7711702	17	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Average						94.44	1.43	0.05		66.67	1.62	0.03		66.67	1.89	0.04		61.11	2.58	0.03		61.11	3.17	0.04		61.11	2.50	0.02		61.11	2.21	0.03		61.11	2.83	0.03		61.11	2.21	0.02	61.11	**2.27**	0.03
Survival Rates						94.44				66.67				66.67				61.11				61.11				61.11				61.11				61.11				61.11			61.11		

Key

HT:	Height
RD:	Root Collar Diameter
Increment:	Increments
Elev.:	Elevation
0 :	Wilted

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APPENDIX C5: Raw Data for *Dodonaea viscosa* planted as control on natural soil without surface cover

Block	Elev.	X	Y	Initial HT (cm)	Initial RD (cm)	Dec Actual HT	Dec Actual RD	Dec Inc HT	Dec Inc RD	Jan Actual HT	Jan Actual RD	Jan Inc HT	Jan Inc RD	Feb Actual HT	Feb Actual RD	Feb Inc HT	Feb Inc RD	Mar Actual HT	Mar Actual RD	Mar Inc HT	Mar Inc RD	Apr Actual HT	Apr Actual RD	Apr Inc HT	Apr Inc RD	May Actual HT	May Actual RD	May Inc HT	May Inc RD	Jun Actual HT	Jun Actual RD	Jun Inc HT	Jun Inc RD	Jul Actual HT	Jul Actual RD	Jul Inc HT	Jul Inc RD	Aug Actual HT	Aug Actual RD	Aug Inc HT	Aug Inc RD
2	667	308023	7717719	18.1	0.26	18.1	0.3	0	0.04	23.2	0.45	0	0	25.1	0.49	1.9	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	669	308126	7717764	60.4	0.6	60.5	0.64	0.1	0.04	54.4	0.65	4.4	0	59.2	0.69	4.8	0.04	63	0.73	3.8	0.04	70.5	0.79	7.5	0.06	75.5	0.83	5	0	79.6	0.89	4.1	0.06	79.6	0.94	0	0.05	84.4	0.99	4.8	0.05
	670	308266	7717753	47	0.34	50	0.6	3	0.06	78.3	0.84	2.8	0.25	81.4	0.85	3.1	0.01	85.3	0.89	3.9	0.04	91.5	0.93	6.2	0.04	95.5	0.96	4	0.03	100	1.02	4.5	0.06	105	1.09	4.8	0.07	109.5	1.14	4.7	0.05
	667	308280	7717724	62	0.5	75.5	0.59	13.5	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	669	308235	7717866	34.4	0.3	44.9	0.34	10.5	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	666	308410	7717912	23	0.4	30	0.44	7	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	679	308416	7717904	13.4	0.2	19.3	0.29	5.9	0.04	19.3	0.33	0	0.04	24.2	0.39	4.9	0.06	28.6	0.43	4.4	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	673	308223	7717861	63.2	0.4	63.2	0.49	0	0.09	63.5	0.51	0.3	0.02	66.5	0.53	3	0.02	70.3	0.57	3.8	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	66	308734	7717841	48.1	0.62	48.1	0.68	0	0.06	50.1	0.7	2	0.02	53.6	0.75	3.5	0.05	59.6	0.79	6	0.04	64.1	0.83	4.5	0.04	68.3	0.89	4.2	0.06	72.2	0.92	3.9	0.03	75.7	0.96	3.5	0.04	79.4	0.99	3.7	0.03
	669	308155	7717775	35	0.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	666	308118	7717753	64.9	0.4	69.7	0.5	4.8	0.1	69.7	0.5	0	0	72.1	0.53	2.4	0.03	78.1	0.55	6	0.02	82.5	0.6	4.4	0.05	85	0.64	2.5	0.04	89.5	0.68	4.5	0.04	92.1	0.7	2.6	0.02	95.4	0.72	3.3	0.02
	669	308015	7717757	48.1	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	666	308026	7717760	35.3	0.26	41.4	0.4	6.1	0.14	45.2	0.48	3.8	0.08	49.5	0.54	4.3	0.06	54.1	0.58	4.6	0.04	60.1	0.62	6	0.04	65.6	0.66	5.5	0.04	68.1	0.69	2.5	0.03	71.4	0.71	3.3	0.02	73.8	0.74	2.4	0.03
	665	308001	7717748	35.4	0.3	35.4	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	664	308159	7717774	63.5	0.65	68.6	0.69	5.1	0.04	73.2	0.73	4.6	0.04	76	0.75	2.8	0.02	80.1	0.79	4.1	0.04	85.8	0.85	5.7	0.06	89	0.9	3.2	0.05	93.1	0.93	4.1	0.03	98.7	0.96	5.6	0.03	103.5	0.99	4.8	0.03
	669	308289	7717833	56.2	0.2	63.1	0.45	6.9	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	668	308429	7717971	16.5	0.2	19.1	0.4	2.6	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	671	308335	7717857	15	0.6	15	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average								3.64	0.06			0.99	0.03			1.71	0.02			2.03	0.02			1.91	0.02			1.36	0.01			1.31	0.01			1.10	0.01			1.32	0.01
Survival Rates						88.89				50.00				50.00				44.44				33.33				33.33				33.33				33.33				33.33			

Total Averages: HT 1.71 (cm), RD 0.02 (cm)

Key

HT: Height
RD: Root Collar Diameter
Increment: Increments
Elev.: Elevation
0 (red box): Wilted

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APPENDIX C6: Raw Data for *Dodonaea viscosa* planted on biosolids treatment on bare surface

Block	Elev. X	Elev. Y	Dec Init HT	Dec Init RD	Dec Act HT	Dec Act RD	Dec Inc HT	Dec Inc RD	Jan Act HT	Jan Act RD	Jan Inc HT	Jan Inc RD	Feb Act HT	Feb Act RD	Feb Inc HT	Feb Inc RD	Mar Act HT	Mar Act RD	Mar Inc HT	Mar Inc RD	Apr Act HT	Apr Act RD	Apr Inc HT	Apr Inc RD	May Act HT	May Act RD	May Inc HT	May Inc RD	Jun Act HT	Jun Act RD	Jun Inc HT	Jun Inc RD	Jul Act HT	Jul Act RD	Jul Inc HT	Jul Inc RD	Aug Act HT	Aug Act RD	Aug Inc HT	Aug Inc RD
668	308044	7717727	40.4	0.4	50	0.44	9.6	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
667	308059	7717754	14.3	0.64	15.1	0.64	0.8	0	15.1	0.65	0	0	18.5	0.66	3.4	0.01	22.1	0.7	3.6	0.04	30.5	0.75	8.4	0.05	34.5	0.79	4	0.04	38.1	0.82	3.6	0.03	41.8	0.85	3.7	0.03	44.9	0.88	3.1	0.03
668	308152	7717780	68.1	0.34	69.1	0.4	1	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
667	308238	7717727	39.5	0.58	39.5	0.65	0	0.07	39.8	0.67	0.3	0.02	45.5	0.7	5.7	0.03	49.7	0.74	4.2	0.04	55.8	0.81	6.1	0.07	59.6	0.85	3.8	0.04	65.2	0.9	5.6	0.05	69.5	0.95	4.3	0.05	73.4	0.99	3.9	0.04
668	308309	7717756	35.8	0.39	35.8	0.43	0	0.04	39.1	0.43	3.3	0	43	0.45	3.9	0	49.1	0.48	6.1	0.03	54.1	0.53	5	0.05	60.1	0.58	6	0.05	65	0.62	4.9	0.04	68.9	0.67	3.9	0.05	71.5	0.71	2.6	0.04
668	308292	7717902	13.5	0.23	20	0.29	6.5	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
670	308423	7717916	19.7	0.2	28.6	0.24	8.9	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
669	308334	7717854	48.7	0.31	48.7	0.45	0	0.14	50.6	0.46	1.9	0.01	54.1	0.5	3.5	0.04	69.6	0.53	15.5	0.03	75.7	0.57	6.1	0.04	78.3	0.61	2.6	0.04	82.5	0.65	4.2	0.04	86.1	0.69	3.6	0.04	89.5	0.72	3.4	0.03
672	308309	7717855	45.5	0.5	45.5	0.58	0	0.08	45.5	0.59	0	0.01	48.9	0.62	3.4	0.03	53.5	0.62	4.6	0	59.7	0.62	6.2	0	63.7	0.65	4	0.03	68.3	0.69	4.6	0.04	72.1	0.73	3.8	0.04	76.8	0.77	4.7	0.04
668	308277	7717808	38.6	0.44	38.6	0.5	0	0.06	38.6	0.5	0	0.08	42.2	0.58	3.6	0.08	46.5	0.63	4.3	0.05	50.4	0.67	3.9	0.04	55.3	0.71	4.9	0.04	60.1	0.75	4.8	0.04	65.1	0.79	5	0.04	70	0.83	4.9	0.04
668	308134	7717766	55.4	0.44	55.4	0.44	0	0	60.1	0.44	4.7	0	63.1	0.51	3	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
669	308314	7717854	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
669	308100	7717745	18.8	0.42	0	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
667	308020	7717728	18.4	0.17	22.8	0.2	4.4	0.03	29.8	0.25	7	0.05	33.6	0.31	3.8	0.06	38.7	0.35	5.1	0.04	44.3	0.41	5.6	0.06	48	0.45	3.7	0.04	52.7	0.49	4.7	0.04	56	0.52	3.3	0.03	60.8	0.58	4.8	0.06
666	308073	7717737	41.9	0.35	45.4	0.4	3.5	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
669	308142	7717788	57.8	0.57	66.1	0.59	8.3	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
668	308260	7717809	52.2	0.44	69	0.63	16.8	0.19	69.2	0.65	0.2	0.02	71.4	0.69	2.2	0.04	75	0.73	3.6	0.04	80.8	0.77	5.8	0.04	85.3	0.81	4.5	0.04	88.3	0.84	3	0.03	93.1	0.88	4.8	0.04	97.4	1.02	4.3	0.14
667	308304	7717848	55	0.47	56.1	0.47	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
668	308444	7717924	30.7	0.6	30.7	0.63	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average / Survival Rates	Dec Inc HT	Dec Inc RD	Jan Act	Jan Inc HT	Jan Inc RD	Feb Act	Feb Inc HT	Feb Inc RD	Mar Act	Mar Inc HT	Mar Inc RD	Apr Act	Apr Inc HT	Apr Inc RD	May Act	May Inc HT	May Inc RD	Jun Act	Jun Inc HT	Jun Inc RD	Jul Act	Jul Inc HT	Jul Inc RD	Aug Act	Aug Inc HT	Aug Inc RD	Total Act	Total Avg HT	Total Avg RD
94.44	3.38	0.05	50.00	0.97	0.01	50.00	1.81	0.02	50.00	2.61	0.02	50.00	2.62	0.02	50.00	1.86	0.02	50.00	1.97	0.02	50.00	1.80	0.02	50.00	1.76	0.02	50.00	2.09	0.02

Key

HT: Height
RD: Root Collar Diameter
Increment: Increments
Elev.:   Elevation
0 :   Wilted

Block	Elev.	Coordinates X	Coordinates Y	December Initial HT (cm)	December Initial RD (cm)	December Actual HT (cm)	December Actual RD (cm)	December Increment HT (cm)	December Increment RD (cm)	January Actual HT	January Actual RD	January Increment HT	January Increment RD	February Actual HT	February Actual RD	February Increment HT	February Increment RD	March Actual HT	March Actual RD	March Increment HT	March Increment RD	April Actual HT	April Actual RD	April Increment HT	April Increment RD	May Actual HT	May Actual RD	May Increment HT	May Increment RD	June Actual HT	June Actual RD	June Increment HT	June Increment RD	July Actual HT	July Actual RD	July Increment HT	July Increment RD	August Actual HT	August Actual RD	August Increment HT	August Increment RD	Total HT	Total RD
2	670	308114	7717755	28.6	0.72	29	0.73	0.4	0.01	30.7	0.74	1.7	0.01	34.7	0.79	4	0.05	38.1	0.81	3.4	0.02	45	0.85	6.9	0.04	49.1	0.89	4.1	0.04	52.2	0.92	3.1	0.03	56.7	0.96	4.5	0.04	61.5	0.99	4.8	0.03		
	669	308186	7717795	20.1	0.54	20.1	0.6	0	0.06	20.4	0.61	0.3	0.01	23.5	0.65	3.1	0.04	27.3	0.69	3.8	0.04	32	0.74	4.7	0.05	35	0.78	3	0.04	38.6	0.81	3.6	0.03	40.8	0.84	2.2	0.03	44	0.87	3.2	0.03		
	668	308345	7717876	9.7	0.2	11	0.3	1.3	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	668	308370	7717888	22.7	0.43	22.7	0.59	0	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308416	7717921	13.8	0.47	14	0.47	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	664	308447	7717940	17.6	0.65	20.8	0.69	3.2	0.04	20.8	0.69	0	0	22.1	0.72	1.3	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308410	7717907	31.3	0.41	39.4	0.41	8.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308363	7717881	4.6	0.3	8.8	0.38	4.2	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	671	308447	7717940	42.8	1.4	46.8	1.4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308241	7717817	15.1	0.61	18.1	0.68	3	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308186	7717950	22	0.73	25.5	0.78	3.5	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308062	7717737	20.6	0.2	23.7	0.23	3.1	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	671	308178	7717786							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308233	7717816	15.1	0.65	19.2	0.65	4.1	0	21.5	0.73	2.3	0.08	24.5	0.76	3	0.03	28.1	0.8	3.6	0.04	35.1	0.85	7	0.05	38.8	0.89	3.7	0.04	43.5	0.93	4.7	0.04	47.9	0.97	4.4	0.04	52.8	1.02	4.9	0.05		
	668	308348	7717872							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	666	308178	7717786							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	668	308062	7717737							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308241	7717817							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	670	308363	7717881							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	667	308410	7717907							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	674	308094	7717893	18.2	0.72	18.2	0.72	0	0	23.3	0.78	5.1	0.06	26.2	0.82	2.9	0.04	30	0.85	3.8	0.03	36.3	0.92	6.3	0.07	41.1	0.94	4.8	0.02	45.1	0.98	4	0.04	49.8	1.03	4.7	0.05	53.8	1.06	4	0.03		
	670	308348	7717872	11.9	0.61	11.9	0.62	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	669	308454	7717777	19.6	0.6	19.6	0.63	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	669	308454	7717777	18.2	0.72	18.2	0.72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	671	308456	7717947	16.6	0.54	16.6	0.54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	671	308459	7717949	14.5	0.32	14.5	0.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Average								1.95	0.04			0.59	0.01			0.89	0.01			0.91	0.01			1.56	0.01			0.98	0.01			0.96	0.01			0.99	0.01			1.06	0.01	1.10	0.01
Survival Rates						100				27.78				27.78				22.22				22.22				22.22				22.22				22.22				22.22				22.22	

Key

HT:	Height	
RD:	Root Collar Diameter	
Increment:	Increments	
Elev.:	Elevation	
0 :	Wilted	

APPENDIX C8: Raw Data for *Leucaena leucocephala* planted on biosolids without surface cover

| Block | Elev. | Coordinates | | December | | | | | | January | | | | February | | | | March | | | | April | | | | May | | | | June | | | | July | | | | August | | | | Total |
| | | | | Initial | | Actual | | Increment | | Actual | | Increment | | Actual | | Increment | | Actual | | Increment | | Actual | | Increment | | Actual | | Increment | | Actual | | Increment | | Actual | | Increment | | Actual | | Increment | | Averages |
		X	Y	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)	HT (cm)	RD (cm)
2	664	308022	771725	35	0.9	35	0.93	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	670	308070	771739	12.5	0.34	12.5	0.54	0	0	13.4	0.6	0	0	18.1	0.64	4.7	0.04	23.6	0.68	5.5	0.04	29.5	0.72	5.9	0.04	31.1	0.75	1.6	0.03	35.4	0.79	4.3	0.04	37.8	0.82	2.4	0.03	41.8	0.86	4	0.04
	676	308175	771783	17.1	0.52	18.1	0.52	1	0	18.1	0.52	0	0	20.2	0.58	2.1	0.06	23.5	0.62	3.3	0.04	27	0.68	3.5	0.06	31.6	0.71	4.6	0.03	35.6	0.75	4	0.04	39.7	0.79	4.1	0.04	43.7	0.82	4	0.03
	673	308243	771784	23.5	0.8	24.5	0.8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	669	308359	771781	5.5	0.4	6.1	0.43	0.6	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	669	308381	771799	15.7	0.5	15.7	0.5	0	0	67.8	1.2	52.1	0.7	69	1.26	1.2	0.06	71.5	1.3	2.5	0.04	76.4	1.36	4.9	0.06	80.7	1.4	4.3	0.04	84.3	1.44	3.6	0.04	87.9	1.49	3.6	0.05	90.8	1.52	2.9	0.03
	670	308438	771940	38.8	0.72	38.8	0.72	0	0	42.5	0.82	3.7	0.1	46.5	0.9	4	1.2	50.5	0.95	4	0.05	56.1	1.01	5.6	0.06	60.7	1.06	4.6	0.05	64.1	1.09	3.4	0.03	67.9	1.13	3.8	0.04	70.1	1.19	2.2	0.06
	670	308431	771928	25.5	0.43	29.8	0.8	4.3	0.37	29.8	0.8	0	0	31.7	0.86	1.9	0.06	35.5	0.9	3.8	0.04	41.1	0.95	5.6	0.05	45.5	0.99	4.4	0.04	46.5	1	1	0.04	48.1	1.07	1.6	0.04	50.1	1.11	2	0.04
	667	308393	771897	19.1	0.38	19.1	0.38	0	0	25.2	0.59	6.1	0.01	28.1	0.63	2.9	0.04	31.5	0.67	3.4	0.04	38.6	0.72	7.1	0.05	41.1	0.75	2.5	0.03	45.1	0.78	4	0.03	47.8	0.82	2.7	0.04	50.8	0.85	3	0.03
	667	308256	771827	19	0.61	19	0.66	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	668	308210	771803	40.5	0.87	42.3	0.89	1.8	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	669	308164	771784	37.6	0.61	40.1	0.66	2.5	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	667	308049	771724	48.1	0.75	48.1	0.77	0	0.02	48.5	0.79	0.4	0.02	53.4	0.8	4.9	0.01	56	0.84	2.6	0.04	63.1	0.9	7.1	0.06	66.4	0.94	3.3	0.04	0	0	0	0	0	0	0	0	0	0	0	0
	665	308196	771796	9.5	0.63	9.5	0.63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	664	308235	771857	19.8	0.75	19.8	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	666	308375	771879	13.5	0.41	13.5	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	674	308440	771929	16.1	0.73	16.1	0.78	0	0.05	20.1	0.8	4	0.02	23.1	0.86	5	0.06	29.1	0.9	4	0.04	33.9	0.95	6.8	0.05	38.4	0.98	2.5	0.03	41.7	1	3.3	0.02	44.5	1.04	2.8	0.04	47.9	1.07	3.4	0.03
	671	308453	771956	17.7	0.41	17.7	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Average	0.62	0.03					3.68	0.05			1.48	0.02			1.62	0.02			2.58	0.02			1.54	0.02			1.31	0.01			1.17	0.02			1.19	0.01			1.69	0.02
			Survival Rates	100.00						38.89				38.89				38.89				38.89				38.89				38.89				38.89				38.89				38.89	

Key

HT: Height
RD: Root Collar Diameter
Increment: Increments
Elev.:   Elevation
0 :   Wilted

APPENDIX D1: SPSS Data input for growth performance of species (Monthly averages)

Block	Treatment	Subjects (Eperimental Units)					
		Dodonaea viscosa			*Leucaena leucocephala*		
		Hieght (cm)	RCD (cm)	Survival Rates (%)	Hieght (cm)	RCD (cm)	Survival Rates (%)
Grass Cover	Natural Soil	2.07	0.03	100	0.67	0.02	100
		1.77	0.02	66.7	1.42	0.02	55.7
		2.72	0.03	66.7	0.84	0.02	55.7
		2.98	0.03	66.7	1.93	0.02	38.9
		2.61	0.03	66.7	1.73	0.03	38.9
		2.08	0.03	66.7	1.22	0.02	38.9
		1.37	0.01	66.7	0.79	0.01	38.9
		1.36	0.02	66.7	0.78	0.01	33.3
		1.29	0.02	66.7	0.67	0.01	33.3
	Biosolids	2.26	0.06	94.4	1.43	0.05	94.4
		3.32	0.03	61.1	1.62	0.03	66.7
		2.83	0.03	61.1	1.89	0.04	66.7
		3.23	0.03	61.1	2.58	0.03	61.1
		4.89	0.04	50	3.17	0.04	61.1
		3.02	0.03	38.9	2.5	0.02	61.1
		2.69	0.03	38.9	2.21	0.03	61.1
		2.93	0.03	38.9	2.83	0.03	61.1
		2.76	0.03	38.9	2.21	0.02	61.1
Bare Ground	Natural Soil	3.64	0.06	88.9	1.95	0.04	100
		0.99	0.03	50	0.59	0.01	27.8
		1.71	0.02	50	0.89	0.01	27.8
		2.03	0.02	44.4	0.91	0.01	22.2
		1.91	0.02	33.3	1.56	0.02	22.2
		1.36	0.02	33.3	0.98	0.01	22.2
		1.31	0.02	33.3	0.96	0.01	22.2
		1.1	0.01	33.3	0.99	0.01	22.2
		1.32	0.01	33.3	1.06	0.01	22.2
	Biosolids	3.38	0.05	94.4	0.62	0.03	100
		.0.97	0.01	50	0.58	0	38.8
		1.81	0.02	50	1.9	0.02	38.8
		2.61	0.02	50	1.26	0.01	38.8
		2.62	0.02	50	2	0.02	38.8
		1.86	0.02	50	1.05	0.01	38.8
		1.97	0.02	50	0.92	0.01	38.8
		1.8	0.02	50	0.76	0.01	38.8
		1.76	0.02	50	0.91	0.01	38.8

APPENDIX E1: Descriptive Statistics – Monthly Average Height Increments (cm)

Type of species (Subjects or Experimental units)	Type of soil (Control and Treatment)	Type of soil surface cover (Block)	Mean	Std. Deviation	N
Dodonaea viscosa	Natural Soil	Grass cover	2.0278	.63431	9
		Bare ground	1.7078	.80563	9
		Total	1.8678	.72241	18
	Biosolids	Grass cover	3.1033	.73882	9
		Bare ground	1.9789	.92271	9
		Total	2.5411	.99610	18
	Total	Grass cover	2.5656	.86743	18
		Bare ground	1.8433	.85179	18
		Total	2.2044	.92304	36
Leucaena leucocephala	Natural Soil	Grass cover	1.1167	.47906	9
		Bare ground	1.0989	.40652	9
		Total	1.1078	.43111	18
	Biosolids	Grass cover	2.2711	.56483	9
		Bare ground	1.1111	.51984	9
		Total	1.6911	.79592	18
	Total	Grass cover	1.6939	.78161	18
		Bare ground	1.1050	.45275	18
		Total	1.3994	.69676	36
Total	Natural Soil	Grass cover	1.5722	.71908	18
		Bare ground	1.4033	.69379	18
		Total	1.4878	.70163	36
	Biosolids	Grass cover	2.6872	.76834	18
		Bare ground	1.5450	.85273	18
		Total	2.1161	.98763	36
	Total	Grass cover	2.1297	.92605	36
		Bare ground	1.4742	.76951	36
		Total	1.8019	.90753	72

APPENDIX E1: Descriptive Statistics – Monthly Average RCD Increments (cm)

Type of species (Subjects or Experimental units)	Type of soil (Control and Treatment)	Type of soil surface cover (Block)	Mean	Std. Deviation	N
Dodonaea viscosa	Natural Soil	Grass cover	.0244	.00726	9
		Bare ground	.0233	.01500	9
		Total	.0239	.01145	18
	Biosolids	Grass cover	.0344	.01014	9
		Bare ground	.0222	.01093	9
		Total	.0283	.01200	18
	Total	Grass cover	.0294	.00998	18
		Bare ground	.0228	.01274	18
		Total	.0261	.01178	36
Leucaena leucocephala	Natural Soil	Grass cover	.0178	.00667	9
		Bare ground	.0144	.01014	9
		Total	.0161	.00850	18
	Biosolids	Grass cover	.0322	.00972	9
		Bare ground	.0133	.00866	9
		Total	.0228	.01320	18
	Total	Grass cover	.0250	.01098	18
		Bare ground	.0139	.00916	18
		Total	.0194	.01145	36
Total	Natural Soil	Grass cover	.0211	.00758	18
		Bare ground	.0189	.01323	18
		Total	.0200	.01069	36
	Biosolids	Grass cover	.0333	.00970	18
		Bare ground	.0178	.01060	18
		Total	.0256	.01275	36
	Total	Grass cover	.0272	.01059	36
		Bare ground	.0183	.01183	36
		Total	.0228	.01201	72