The use of various soil ameliorants and indigenous grasses, in the rehabilitation of soil from open cast coal mines in Mpumalanga, South Africa

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Declaration of originality

The experimental work described in this thesis was carried out in the Discipline of Grassland Science, University of KwaZulu-Natal, Pietermaritzburg, from January 2002 to March 2004, under the supervision of Dr J.E. Granger, Prof. K.P. Kirkman and Prof. M.D. Laing.

These studies represent original work by Christy M.W. Webb and have not otherwise been submitted in any form for any degree or diploma to any university. Where use has been made of the work of others it is duly acknowledged in the text.

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Abstract

A series of pot trials were undertaken to test the growth of indigenous grasses (*Themeda triandra* and *Cynodon dactylon*) on mine capping soil, treated with various soil ameliorants. The capping soils were obtained from open cast coal mines (Optimum Mine and Syferfontein Mine) in the Mpumalanga Highveld, south of Witbank. However, because mine soil was not available at the commencement of the project, the initial pot trial used soil from the Umlazi Landfill in Durban.

The trials were the Umlazi Landfill Trial, Microbe Trial, Legume Trial and Fly Ash Trial. For the Umlazi Landfill Trial, landfill top and subsoil was used along with fertilizer, sewage sludge, K-humate, lime and microbes. The soil ameliorant treatments for the Microbe trial were *Trichoderma harzianum* (EcoT), *Bacillus subtilis* Strain 69 (B69) and *Bacillus subtilis* Strain 77 (B77), for the Legume Trial, *Medicago sativa*, phosphorus and/or potassium were applied. For the Fly Ash Trial, lime and fly ash were introduced.

From the Landfill trial it was shown that fertilizer and sewage sludge significantly increased the above ground, below ground and total biomass of *T. triandra*, further, there were no significant treatment differences between fertilizer and sludge. The lime treatment for this trial, surprisingly, significantly reduced below ground biomass but the application of microbes (B69 and EcoT) alleviated this negative effect. However, in the Microbe Trial the microbes (EcoT, B69 and B77) had a negative or no effect on the biomass of *T. triandra* and *C. dactylon*. In the Legume Trial it was shown that the above ground biomass of *T. triandra* was significantly reduced when grown with *M. sativa*. The Fly Ash Trial revealed that the lime and fly ash treatments had no effect on the biomass of *M. sativa* and *T. triandra*, and they did not maintain a reduction in soil acidity.

The results therefore indicated that either organic fertilizer or sewage sludge could be used to significantly improve the growth of *T. triandra*. It was also suggested that lime not be applied to soils with an acid saturation of approximately 1%, as this could retard plant growth. The application of microbes and the growth of a legume with grass, although both have been recorded to have beneficial effects in aiding plant growth, in the short-term however, the application of *T. harzianum*, *B. subtilis* Strain 69 and 77 applied to the soil while growing *T. triandra* and *C. dactylon* and the growth of *M. sativa* with *T. triandra* is not recommended.

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Table of units and abbreviations

Table 1: Summary of units

Units	Description
t	tonne
Mt	Megatonne
g	gram
mg	milligram
kg	kilogram
L	Litre
mL	millilitre
mm	millimetre
c.f.u	colony forming unit
AU	Animal unit
ppm	parts per million
cmol	centimols

Table 2: Summary of abbreviations

Abbreviations	Description
nd.	no date
nl.	no location
S.O.V	Source of variation
vr	variance ratio
cv	coefficient of variation

1. General Introduction

1.1. INTRODUCTION

Open cast coal mining disturbs extensive areas in South Africa. The mining process is destructive and mines are legally required to take steps to mitigate and repair the damage caused. Therefore, before an area is mined, the topsoil is removed and stockpiled at a selected site (Lyle 1987). Once the coal has been mined, the overburden is deposited, shaped and then the topsoil is replaced on top of the overburden and revegetated (Lyle 1987).

Revegetation is closely associated with rehabilitation, and there are various problems, which hinder revegetation and therefore rehabilitation, for example, soil acidity, infertile topsoil (capping soil) and soil compaction. However, the aim of rehabilitation is to restore the affected areas to their previous condition or better than . Only then are mines permitted to sell the land. Therefore a research programme (Coaltech 2020) was formed by the major mining companies, the national electricity generating company, universities, the CSIR, organised labour and the state, in order to address problems experienced during mine rehabilitation and other concerns. Two open cast coal mines were chosen in order to research mine rehabilitation. The two mines were Optimum Mine and Syferfontein Mine. This study therefore primarily used capping soil, from these mines.

In the study three problems (soil compaction, acidity and low nutrient levels) experienced during mine rehabilitation were reviewed, however, the research focused on the problems of low nutrient levels in the soil and soil acidity.

The aim of the study was therefore, to promote plant growth by improving the nutrient levels and /or the pH of the soil by adding various soil ameliorants. The hypothesis was therefore that the use of various soil ameliorants would enhance the balance of plant available nutrients, ameliorate the Ph and hence promote plant growth.

The scope of the project was to measure the effect of certain soil ameliorants (sewage sludge, fertilizer, lime, fly ash, soil microorganisms, K-humate, and a legume) on the growth of *Themeda triandra*, *Cynodon dactylon* (Seagreen) and *Medicago sativa* (cultivar Sequel) when grown in top soil from Syferfontein Mine and Optimum Mine (except for the first trial).

The nomenclature for all species used and identified in this project was found in Arnold & De Wet (1993). The thesis follows the referencing guidelines of the Journal of Range and Forage.

1.2. SEQUENCE OF THE RESEARCH PROCESS

The research process for the project was initiated after identifying soil problems (soil compaction, low nutrient levels and acidity) experienced on the mines (Syferfontein Mine and Optimum Mine). Certain soil ameliorants were chosen in order to attempt to alleviate these problems and in so doing, to maximize grass growth.

The first trial, Umlazi Landfill Trial, investigated the effect of six ameliorants on the growth of *Themeda triandra,* the Treatments were fertilizer, sewage sludge, soil microorganisms, K-humate, lime and top and subsoil. Due to mine capping soil not initially being available, soil from Umlazi Landfill near Durban was used. This soil is considered poor (low nutrient levels and organic matter) as is the mine capping soil that was used later in the project. From the results of this trial it was decided to further investigate the treatments of lime and microbes.

Following the Umlazi Landfill Trial a brief species composition survey was done on three coal mines in the Witbank area. The timing of the survey coincided with many grasses being in seed, therefore more readily identifiable. The mine holdings surveyed were Syferfontein Mine, Optimum Mine and Kromdraai Mine. The aim of this survey was to determine which species were present in undisturbed veld and in areas that had undergone the rehabilitation processes for five or more years, therefore suitable sites were chosen on all three mines. An important grazing grass in the area is *T. triandra*, and as this was found in the area, and as the mined areas are possibly going to be used for grazing once they have been rehabilitated, it was decided to continue to use *T. triandra* in the project pot trials. *Cynodon dactylon* was also chosen as it was present in the area and is a spreading grass, therefore beneficial for erosion prevention.

The second pot trial, Microbe Trial, was run using Optimum Mine and Syferfontein Mine capping soil (as were any further trials) and *Themeda triandra* and *Cynodon dactylon* (Seagreen), with three microbes as the treatments. Although *C. dactylon* did grow in the soil it was decided to only use *T. triandra* in further trials, as *C. dactylon* was inconvenient to harvest and did not register significant differences whereas *T. triandra* did.

The third trial, Legume Trial, was then run using the treatments *Medicago sativa* (lucerne), phosphorus and potassium on the Optimum Mine soil and lucerne and phosphorus on the Syferfontein Mine soil.

The fourth trial, Fly Ash Trial, compared the effects of lime and fly ash on the growth of *Themeda triandra* and *Medicago sativa.* As the trial was also designed to test the effect on the soil pH, only Optimum Mine soil was used as Syferfontein Mine soil was not found to be acidic.

1.3. STRUCTURE OF THESIS

Chapter 1 is a general outline of the reasons for the project and the project aims.

Chapter 2 is the literature review that highlights three soil problems that occurs when rehabilitating mined areas. These problems (soil compaction, low nutrient levels and soil acidity) and possible solutions to these problems are discussed in depth in this chapter.

Chapter 3 describes the area in which Optimum Mine and Syferfontein Mine are situated and the species composition of the area. Although the species survey was done after the initial pot trial, this chapter was placed before the Umlazi Landfill Trial chapter, in order for the pot trial chapters to be placed consecutively. Chapter 3 also introduces the species that were used in the pot trials and demonstrates the range of species that ideally need to be present once rehabilitation has occurred.

Chapters 4, 5, 6, and 7 deal with the pot trials and are written in chronological order. These chapters all contain a summary of results and a discussion at the end of each chapter.

Chapter 8 gives a diagrammatical representation of the project, along with overall conclusions and recommendations. Further research opportunities are also suggested and the end of the chapter.

2. Selected problems and solutions when rehabilitating open cast coal mine soil

2.1. INTRODUCTION

The terms 'open cast', 'open-pit', 'surface', and 'strip mining' are often used interchangeably, when referring to how minerals are mined. However, strip mining is mainly used in reference to coal mining (Coal Mining 2004). These methods all involve the removal of the top layers of soil and rock to expose the coal (Coal Mining 2004), and are all environmentally destructive because they disturb landscapes, and destroy the natural vegetation and the original soils found in an area (Fresquez & Lindemann 1982). In South Africa it is a legal requirement for mines to rehabilitate the areas affected, after mining has finished, (Chapter VI of the Mineral Act 50 of 1991; Kidd 1997). According to the World Coal Institute (WCI) (2003a), it is now possible to rehabilitate mined areas to their original or better than their original conditions, due to the technology now available. However, rehabilitation is not only important in order to make these areas environmentally stable, but also to ensure that they can be restored to economic viability again. According to Bellairs (1998) mine rehabilitation has predominantly focussed on the rapid and economic establishment of plants on hostile media. In Australia the plants being established were mainly exotic pasture species while relatively few indigenous species were used (Ryan 1995; Burns 1999). According to WCI (2003a) these areas, once rehabilitated, could be used for forestry, recreation, agriculture or game parks. Rehabilitation of grassland/ veld is said have occurred when the degraded veld has been restored to a productive and stable condition (Trollope *et al.* 1990).

However, coal mining disturbs vast areas. Syferfontein Mine is an example of a strip mine situated in Mpumalanga Province, South Africa. In 2003, the total area which had been strip mined was 840 ha, while the total planned area to be mined is 1000 ha. Another mine in Mpumalanga is Kromdraai Mine, which plans to mine about 2000 ha.

Mining companies do try to mitigate the damage to the environment that will inevitably be caused by mining. An example of how a mine can aid in rehabilitation and explain why the mining process is so damaging to the environment is Syferfontein Mine operations. Firstly, before mining occurs the topsoil is removed from the area that is to be mined, and from the area where the infrastructure is to be built. The soil is then stockpiled to be used later in the rehabilitation of these areas. At Syferfontein Mine a box cut (i.e. an oblong hole) is dug using trucks and shovels. The material removed from above the coal is stockpiled and called box cut spoils. After the initial box cut, draglines (Fig. 2.1) can then be used to mine in strips. The newly stripped overburden is placed into the area that had just being mined. Once the overburden spoil has been shaped, topsoil is spread over it, fertilized and reseeded with a mixture of seeds (*Chloris gayana*, *Digitaria eriantha*, *Eragrostis curvula* and *Eragrostis teff*). Drilling and blasting of the overburden occurs before dragline mining if the overburden is hard. Once the coal is exposed it is also drilled, blasted and loaded onto rear dump trucks. These then take the coal to the crusher (Walmsley Environmental Consultants (Pty) Ltd. 2000). From this example it is possible to appreciate how destructive mining is, but by stockpiling the topsoil before mining commences and then spreading it over disturbs areas, the mine companies try to ensure a better medium for plant growth when rehabilitation occurs.

Mpumalanga Province contains coal reserves, and in 1994, 84% (160 million tonnes) of South Africa's total coal production was supplied by 56 mines in this province (Meec growing sectors 2004). These mines all ultimately need to be rehabilitated and because this province is classified under Acocks (1975) as Veld Type 61, Bankenveld, which is false grassland, this is then the vegetation that should ideally be used in the rehabilitation of these mined areas. There are various advantages of using indigenous vegetation when rehabilitating an area. According to Majer (1990) these areas can be used to conserve biodiversity, as a source of indigenous seed and as migratory corridors for fauna.

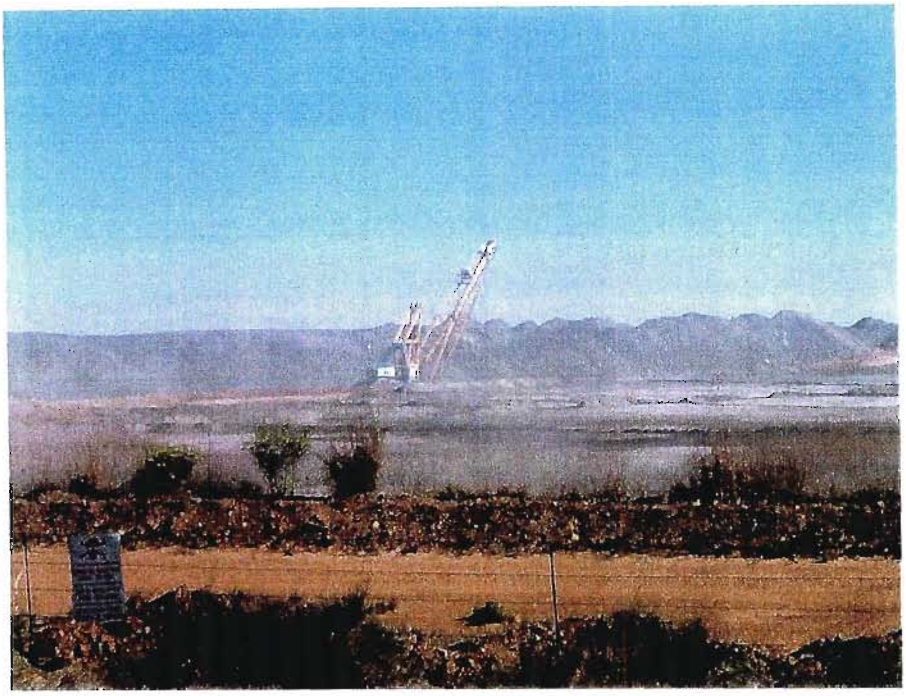

Figure 2.1: A dragline working at the Optimum Mine in Mpumalanga, South Africa.

2.2. GRASSLANDS

One category of plants used in mine rehabilitation and land rehabilitation in general are grasses and since many mines are situated in the Grassland Biome of South Africa, these mines should ideally be rehabilitated back to grassland. South Africa has approximately 343000 km^2 of grassland, which is about 16.5 % of South Africa's total area (Rutherford & Westfall 1986).

Grasslands in South Africa have been divided into six types by Tainton (1999); the humid fire climax grassland, fire climax grassland of potential forest areas, fire climax grasslands of potential savanna areas, climatic climax grassland, climatic climax grassland at low elevations and climatic climax grasslands at high elevations. Grassland is described as the climax vegetation type for these areas. Trollope *et al.* (1990) described a climax vegetation as the plant community which can reproduce itself indefinitely under prevailing environmental conditions.

South African grasslands are further divided into sourveld, sweetveld and mixedveld (Tainton 1999). Sourveld is defined as grassland that can only be utilized for a part of the year without licks, as the forage becomes unpalatable and less nutritious as the plants reach maturity (Trollope *et al.* 1990). Sweetveld, on the other hand, can be utilized all year, as the plants remain palatable and nutritious even at maturity, or different plants become acceptable throughout the year at different times (Trollope *et al.* 1990). Mixedveld is the intermediate between sweet- and sourveld (Tainton 1999). Sweetveld is present in areas with relatively low and erratic rainfall. This results in a lower carrying capacity (ha AU^{-1} $annum^{-1}$) than sourveld, which has higher rainfall and more regular and rapid plant growth, and therefore a higher carrying capacity (Tainton 1999). Although sour grasses dominate sour grasslands or veld, these are not all as unpalatable as *Aristida junciformis* (van Oudtshoorn 1999). Huntley (1984) found that one of the most important grass species in these systems was *Themeda triandra*, which is referred to by van Oudtshoorn (1999) as one of southern and eastern Africa's most important grazing grasses.

Grasslands vary in several ways, e.g., species composition, rainfall and location, but in general grasslands are potentially more productive in terms of carrying capacity than other South African biomes, e.g., Karoo, Fynbos, Forest and Savanna (Tainton 1999). According to Tainton (1999) grassland carrying capacity ranges from 1-5 ha AU^{-1} $annum^{-1}$, while the next highest carrying capacity is found in savanna, which ranges from 4-35 ha AU^{-1} $annum^{-1}$. Grasslands are therefore important for agricultural and economic reasons.

Grasslands are important agriculturally and environmentally. They support a diverse suite of floral species, many of which are endemic, rare and/ or endangered (Scott-Shaw 1999). According to Scott-Shaw (1999) Mistbelt, Montain, Subalpine, Pondoland Coastal, Coastal and Ngongoni Grasslands have a high conservation priority. This is not only because grasslands are hosts to many currently threatened species (Scott-Shaw 1999), but also because grasslands are under constant threat due to an increase in agriculture, urbanization, industrialization (Rutherford & Westfall 1994) and forestry (Carrere 2000). This is because in South Africa the wool, dairy and beef industries rely heavily on this biome, while the Grassland Biome also has the greatest number of urban areas and some of the world's deepest mines (Rutherford & Westfall 1986).

In South Africa less that 2% of the Grassland Biome is being conserved (Rutherford & Westfall 1994). Uys (2000) predicts that this percentage will not increase any time soon, due to lack of suitable land needed to create conservation areas, and insufficient funding. Apart from the plant diversity, there are also endangered animals from large ungulates, e.g., White Rhino (Owen-Smith 1999) to smaller animals, e.g., Blue Swallow, Oribi and Striped Weasel that rely on this biome (Bishop 2003).

There are various items of State and provincial legislature, which are aimed at ensuring the conservation and protection of South African grasslands. An example of which is the Conservation of Natural Resources Act (Act 43/ 83). This Act was instigated in order to promote the protection of soil production, South Africa's water resources and to eliminate alien invasive weeds (Snyman 1999). Agenda 21 also promotes the ethos of sustainable development. This promotes the sensible use of resources, so they can meet the need of current and future generations (Anon. 1998). Although Agenda 21 focused on meeting human requirements, it is also recognises that aspects such as biodiversity, the need to combat desertification and the need for rehabilitation are important in order that systems be sustainable (Anon. 1998).

However, in the coal mining industry there are various problems, which may hinder the process of land rehabilitation. For example, soil compaction, acidity and poor nutritional levels in the soil cause major stress to growing plants. Since the rehabilitation process involves replacing topsoil, and planting grass seed and trees (WCI 2003a), it may be necessary for the soil to be ameliorated appropriately to ensure the emergence and establishment of the desired species.

2.3. SOIL PROBLEMS

Capping soils used for rehabilitation have generally lost many of their former attributes, for example, there is a loss of soil structure, organic matter, physical integrity and their biological processes have been disturbed (Fresquez & Lindemann 1982). This occurs because before mining commences the topsoil (sometimes including the B and C horizons) is removed and stockpiled for a number of years (Fresquez & Lindemann 1982). Moreover, during rehabilitation heavy equipment is used, resulting in compaction (Fulton & Wells nd.).

2.3.1. Compaction

One of the problems experienced in the rehabilitation of open cast coal mines is soil compaction. This problem is aggravated by the extensive use of large vehicles necessary for rehabilitation of the mines (Fulton & Wells nd.). Investigations of soil compaction on yields of cotton have shown that a reduction in wheel traffic increases cotton yields (Dumas *et al.* 1973). Croplands (maize) that had been mined for coal using the open cast system and then rehabilitated also did not obtain the high yields achieved before mining occurred (Fulton & Wells nd.). This was attributed to be directly due to the poor physical condition of the soil after rehabilitation, which was caused by heavy equipment (Fulton & Wells nd.). It is initially important however, to understand what soil compaction is, and then how it affects plant growth.

Soil volume consists of the solid soil grains and the pores between the grains. The larger pores are filled with air while the smaller are generally filled with water. Soil compaction occurs when the total air filled pore space in relation to the soil volume, is not sufficient for maximum plant growth. Soil compaction can be measured in terms of porosity and density, penetrometer resistance and water infiltration (Chancellor 1977). There is however, a difference between soil compaction and hardsetting soils. Soil compaction is caused by the application of mechanical forces to the soil, while hardsetting soils also restrict seed emergence and root penetration, this is due to the nature of the soil, rather that external forces (SSSA 1997).

Soil compaction inhibits the growth of roots in various ways. For example, it creates a poorer environment for roots to grow because it reduces aeration, slows the movement of water and nutrients and results in the accumulation of toxic gases and root exudates (Brady & Weil 2002). It also restricts or even prevents root penetration into to the soil. As the root's main function is to acquire water and nutrients for the plant, the growth of the roots is directly linked to the ability of the plant to utilize the water in a certain volume of soil and visa versa (Chancellor 1977). Another effect of soil compaction is that seedling emergence decreases when soil is compacted partially due to insufficient availability of oxygen required by the seeds to germinate. The biological activity around the roots also decreases, as the already limited oxygen is used up while carbon dioxide increases. With the decrease in porosity the diffusion of gasses is restricted (Chancellor 1977). All these factors retard root growth.

Soil compaction negatively affects root growth and this causes great stress for the plants. In general more money needs to be spent when planting in compacted soils than in non-compacted soils. This is because the plants need to be irrigated more frequently, but due to the compaction the soil pores are reduces and infiltration of the water takes longer, therefore plants are more likely to become waterlogged, and once again oxygen levels decrease in the soil. Waterlogging relates to another problem, which is that soils are more readily compacted by machinery when moist (Chancellor 1977). These factors therefore need to be taken into consideration when rehabilitating large areas, as in the case of open cast coal mines where machinery is used.

Another cause of soil compaction is plant roots. Compaction by roots occurs when the roots penetrate the soil. If the pore space is not large enough to accommodate the root cap then, as the soil particles are pushed aside, compaction occurs around the root (Brady & Weil 2002). Obviously the larger and longer the root, the greater the soil compaction, i.e. tree roots will cause more compaction than grass roots. However, it is necessary to promote plant growth, because, although root growth may cause compaction on a small scale, it also alleviates compaction when the roots decay (Chancellor 1977). This is because the soil becomes more permeable to water and air due to the root channels. The decaying material improves the soil structure and thereby can also increase the soil's porosity. Some soils however, tend to have low porosity with or without root growth (Chancellor 1977). Certain conditions seem to promote compaction. High acidity, poor drainage and low nitrogen supply could cause the roots not to decompose and this leads to the excessive accumulation of dead roots in the soil (Schroeder & Sprague 1994).

Therefore, to reduce or prevent soil compaction, heavy traffic needs to be restricted where possible, when rehabilitating soils (Fulton & Wells nd.; Brady & Weil 2002). If the soil conditions are acidic, their pH needs to be increased, possibly by lime (Miles & Manson 2000; Brady & Weil 2002). This is because although acidic soil does not cause soil compaction, acidity does tend to amplify the problem when it occurs (Chancellor 1977; Schroeder & Sprague 1994), although this is not the main reason to lime. To alleviate soil compaction in rehabilitation, the area needs to be revegetated. This will not only relieve compaction due the plant roots penetrating into the soil and leaving channels when they decompose (Chancellor 1977), but it will also increase the soil organic matter thus improving the soil's structure (Chancellor 1977; Schroeder & Sprague 1994) and attracting soil organisms, e.g., earthworms (Brady & Weil 2002). This allows for improved water infiltration, aeration, greater nutrient availability for plants and an overall healthier soil.

2.4. NUTRIENTS

The availability of plant nutrients in the soil is referred to as soil fertility (Bornman *et al.* 1989). There are various sources of plant nutrients (Schroeder & Sprague 1994). Firstly, they are made available from the decomposition of mineral fragments that make up the soil. The most important of these mineral fragments are clay and silt, whilst sand is chemically inert. Clay and organic matter make up most of the soil's mineral colloids. Secondly, nutrients may be supplied by the decay of organic matter (Schroeder & Sprague 1994). Nutrients are also added to the system by the deposition of dung and urine by animals (e.g., cattle) and the application of fertilizer and lime, while nutrients are lost predominantly through the removal of plant material and animal products off the system, and leaching (Miles & Manson 2000).

As with all plants, grasses require macronutrients to be supplied from the soil. If they are deficient or unavailable then they need to be added to the soil or applied as foliar spray.

Macronutrients are nutrients that are required by plants in large amounts (Brady & Weil 2002). In *Eragrostis curvula* typical amounts of N, P, K, Ca and Mg in 10t dry matter are 160, 15, 140, 25 and 14 kg respectively (Miles & Manson 2000). Air and water provide hydrogen (H), oxygen (O) and carbon (C) and are generally present in soils. Iron (Fe) is also very important for plant growth but is rarely limited (Schroeder & Sprague 1994). Macro and micronutrients are important for the healthy growth of plants, three of these macronutrients which are generally added to the soil are N, P and K. However, in order for a plant to take up nutrients from soil solutions, the nutrients need to be water-soluble or converted into water-soluble forms (Schroeder & Sprague 1994).

Nitrogen is generally available to the plant in soils as NO_3^-, NH_4^- and as urea $(CO(NH_2)_2$ (Miles & Manson 2000). However the absorption of $(CO(NH_2)_2$ by plant roots is usually slow (Mengel & Kirkby 1987). Microbes are able covert atmospheric nitrogen (N_2) into usable plant ammonia (NH_3) by a process called nitrogen-fixation (Parsons 1997). However, it has been found that in perennial pastures, the topsoil contains a large amount of N, but 98% of this N is tied up in soil organic matter, so it is not readily available to the plants. This N is made available to the plants when microbes decompose the organic material, in a process called mineralisation (Miles & Manson 2000). When estimating the release of N into the soil the carbon: nitrogen (C: N) ratios of selected organic materials can be used as guidelines (Table 2.1).

Table 2.1: Approximate carbon: nitrogen (C: N) ratios of some organic substances (Tisdale *et al.* 1985; Haynes 1986; Whitehead 1986)

Organic substance	C:N ratio
Clover roots and herbage	12-20:1
Grass roots fertilized with 350 kg N ha annum^{-1}	25-30:1
Grass roots and herbage fertilized at low rates	40-50:1

This is useful to know because C: N ratios that are less than 25:1 result in a rapid release of N (mineralization), while C: N ratios greater than 30:1 have slower mineralization rates (Miles & Manson 2000). Knowing the amount and the rate of usable N being released in to a system is important when determining fertilizer application programmes. The normal range of %N in dry plant matter is 1% to 5% (Miles & Manson 2000).

In South Africa, many of the soils are deficient in P, and trying to correct this deficiency in pasture and croplands is expensive. Phosphorus exists in the soil in both inorganic and organic forms. When in inorganic form, it is found in combination with numerous other elements, e.g., Ca, Al, and Fe. However, many of these are insoluble. An increase in soil organic matter also increases the level of P in a system, as it can be found in humus, and plant and microbe residues (Miles & Manson 2000).

Phosphorus is essential for plants as it is present in adenosine triphosphate (ATP) and many other molecules, which are required in most of the plants processes, e.g., photosynthesis and nutrient uptake by roots. The total P content in dried leaf tissue is about 0.2%- 0.4% (Brady & Weil 2002). Phosphorus is also important in fixing N (Brady & Weil 2002), through the formation of root nodules, which contain N fixing rhizobia (Andrew & Johnson 1978), and also it also promotes root growth (Brady & Weil 2002). Grasses tend to utilise P more efficiently than legumes, because of their extensive root system (Miles & Manson 2000). It has been found that to maximize N fixation, higher levels of P are required than are necessary for maximum dry matter production. This is interesting because P becomes more soluble in response to the increase in NH_4^+ caused by the mineralization of N (Miles & Manson 2000).

Most southern African soils contain sufficient amounts of plant available K for initial production of a pasture (Miles & Manson 2000). However, this usable K is only 1-2% of the total K in soil (Brady & Weil 2002). Potassium is present in the soil in four forms. Firstly, it is found in primary mineral structures. This form is unavailable to plants. Secondly, there is non-exchangeable K in secondary minerals, which is slowly made available to plants. The third and fourth forms of K, which are readily available to plants, are found as soluble K and exchangeable K. Potassium is exchangeable on the surface of soil colloids (Brady & Weil 2002). All plants are able to utilise K, which is readily available, but many grasses are able to use slowly available K, if they possess fine fibrous roots (Brady & Weil 2002).

The presence of nutrients in the soil cannot be understood in isolation because, the presence and concentration of one nutrient can influence the availability of another. In the case of K, Miles & Manson (2000) suggested that there is a significant relationship between K and N, Mg, Ca and Na. An example of this is when sufficient K is available, more K is taken up as the supply of N increases. This also tends to increase the required K concentration required for maximum yield, when N levels increase (Miles & Manson 2000).

There are various factors that limit the intake of nutrients by plants, one of these is soil acidity. Soil acidity is generally measured as pH, which reflects the active H^+ in the soil, therefore the lower the pH the more H^+ is present in the soil and therefore the higher the acidity (Bornman *et al.* 1989; Miles & Manson 2000). Although H^+ is seldom harmful to a plant's roots, the decrease in soil pH, increases the amount of soluble Al^{3+}, which can restrict root growth, thereby limiting a plant's access to water and nutrients (Miles & Manson 2000). Soil acidity also reduces mineralization. It is suggested that this is due to hydrogen and aluminium toxicity and Ca deficiency (Adams & Martin 1984). Ameliorating the soil with lime is a common method of reducing soil acidity, and depending of which form of lime used Ca and Mg can be added by applying calcitic and dolomitic lime respectively (Schroeder & Sprague 1994; Miles & Manson 2000; Brady & Weil 2002).

The supply of the nutrients should be proportional to the amount required by the plant, that is, more is not always better. The balance of these nutrients is also essential for healthy plant growth (Schroeder & Sprague 1994). It is therefore essential for any manager of a vegetation system to understand nutrients and their role in the system when wanting to improve plant growth by ameliorating the soil.

2.5. SOIL AMELIORANTS

2.5.1. Fertilizer

When rehabilitating mines, one objective of paramount concern is that rapid plant growth and cover (revegetation) is required (Fresquez & Lindemann 1982; Topper & Sabey 1986). There are two forms of fertilizers, inorganic and organic that can be used to promote plant growth. Fertilization using inorganic fertilizers is a common method used to promote growth (Topper &

Sabey 1986). In Australia, areas being rehabilitated are fertilized with high application rates of inorganic fertilizer for at least five years and once plants have been established, they are also grazed, weeds are controlled and erosion damage is repaired (Hannan & Gordon 1996). However, although inorganic fertilizers are commonly used in mine rehabilitation much of the information gathered about inorganic fertilizers and their effect on grass and grasslands has been obtained from agricultural grazing systems, where they are extensively used. The three main plant nutrients used in inorganic fertilizers are N, P, and K. these nutrients can be applied 'straight' or in mixed forms (N and P or N, P and K) (Bornman *et al.* 1989; Miles & Manson 2000).

In South Africa N fertilizers are based on urea (46 %N) ($CO(NH_2)_2$), ammonium nitrate (35 % N) (NH_4NO_3) and ammonium sulphate (21 % N, 24 %S) (NH_4SO_4) (Bornman *et al.* 1989; Miles & Manson 2000). The extent to which N fertilizers will increase the dry matter (DM) yield of grass depends on the species, growth conditions and the frequency of defoliation. *Eragrostis curvula* can produce about 60 kg DM kg^{-1} N (Tainton *et al.* 1981), while irrigated Italian ryegrass produced about 25-34 kg DM kg^{-1} N (Eckard 1989). Nitrogen fertilizers also increase the acidity of the soil by varying degrees, so this is important to know when deciding which fertilizer to use. The acidity caused by four common fertilizers are shown in decreasing order: ammonium sulphate > ammonium sulphate nitrate > urea > limestone ammonium nitrate (LAN). Ammonium sulphate has about double the acidifying effect of the other N fertilizers shown, and Ca and Mg my also be more readily leached when NH_4SO_4 is used compared to the others (Miles & Manson 2000).

The commercial P fertilizers fall into two groups, 'readily-available' (water soluble) and 'sparingly soluble' forms. Some common water-soluble fertilizers are: superphosphate (single supers) (8.3-10.5 %P, 20-22 %Ca, 10-12 %S) double superphosphate (19.6 %P, 16 %Ca, 3 %S) and ammoniated superphosphate (AMP) (12.2 %P, 3.8 %N, 17.1 %Ca, 9.8 %S) (Bornman *et al.* 1989; Miles & Manson 2000). Rock phosphates, partially acidulated rock phosphates and thermophosphates, belong to the "sparingly soluble' forms of inorganic P fertilizers. Rock phosphates vary greatly in their value as fertilizer due to their origin. Rock phosphates and similar fertilizers vary in their solubility due to their nature, the soil they are being applied to, particle size and soil acidity. The fertilizers become more soluble as the acidity increases and the exchangeable Ca decreases, while the application of NH_4^+ fertilizers stimulates greater P absorption than NO_3^- fertilizers (Miles & Manson 2000). However, not all the P applied to crops is taken up. In the case of water-soluble P fertilisers only about 10-30 % of the P is utilised by the plants in during the year, while most of the P is retained by the soil (Bolland & Gilkes 1998).

The cheapest and most widely used K fertilizer is potassium chloride (KCl)(murate of potash) which contain 50 %K (Bornman *et al.* 1989; Miles & Manson 2000). Potassium naturally occurs in salts and mixtures of minerals and salts (Bornman *et al.* 1989). The K requirements between species varies greatly, however legumes and grasses generally have a minimum of 1.5 -3.0 % K in their dry matter (Miles & Manson 2000). Potassium appears to have a strong relationship with N. Prins & Den Boer (1985) showed that there was an increase in the recommended herbage K concentration in ryegrass from 19.7 g DM^{-1} when N herbage concentration was 8 g DM^{-1} to 38.1 g DM^{-1} when N herbage concentration was 48 g DM^{-1}.

It is therefore necessary to understand the relationships between the various plant nutrients, and their effect on the ability of plants to utilize them to improve their growth, when implementing a fertilizer regime. The use of fertilizers to maximise plant production is essential in agriculture, but the quality of the produce is also important.

In grazing systems it is important for cattle to have sufficient forage, preferably of good quality. One of the ways to provide such requirements is by fertilization. In sourveld areas where intensive farming is practiced, a shortage of nitrogen is one of the main limiting factors in plant growth (Barnes *et al.* 1986). Along with this, grasses also decrease in nutritional value towards the end of the growing season (Barnes *et al.* 1986). It was found by Barnes *et al.* (1986) that when the grassland is fertilized with nitrogen supported by phosphatic fertilizer, the herbage production and the nutritional value of the grass increases.

The problem with the application of fertilizer is that it may result in an undesirable change in species composition in the grassland. The desirable species tend to be replaced by *Eragrostis* sp., mainly *E. curvula*. This change appears to be permanent, unless quite severe methods are used to alter it (Barnes *et al.* 1986). An example of such a method would be to kill the existing grass sward, using herbicide, and to then reseed using desirable species. Although the species change to *Eragrostis* sp. does not necessarily mean a decrease in animal production, the quality of the grass declines if the fertilizer application is stopped (Barnes *et al.* 1986). In a case where legumes were used in order to increase the soil nitrogen, it was found that the legume disappeared in about two to three years (Edwards 1983), and in a follow up study done by Barnes *et al.* (1986) the areas had been invaded by *E. plana*, *E. capensis* and *A. junciformis*. In a long-term fertilization experiment in KwaZulu-Natal, Fynn & O'Connor (in press), showed that with increasing levels of nitrogen fertilizer applications, all plant species (grasses and forbs) decreased in abundance except *E. curvula* and *Panicum maximum*. *Eragrostis curvula* tended to dominate more when N was applied by itself, while *P. maximum* dominated when N and P were applied (Fynn & O'Connor in press). Another interesting aspect is that N in the form ammonium sulphate (NH_4SO_4) promoted *E. curvula* and *Tristachya leucothrix*, while *Cymbopogon excavatus* was abundant when ammonium nitrate (NH_4NO_3) was applied (Fynn & O'Connor in press). Fynn & O'Connor (in press) also found that when lime was applied with N fertilizer, *E. curvula* and *T. leucothrix* decreased in abundance, while *C. excavatus*, *Setaria nigrirostis*, *Hyparrhenia hirta* and *Heteropogon contortus* increase in abundance, showing that some species appeared to be differentially sensitive to soil acidity.

It is therefore important to realise that whilst fertilizers may promote plant growth, they may also promote species change and/or domination. This needs to be understood when rehabilitating an area, and fertilizer use is being considered.

2.5.2. Soil microorganisms

The living fraction of the soil consists of plant roots, microbes and invertebrates. The soil microbes are responsible for most of the conversion of the dead roots into humus (Schroeder & Sprague 1994). Humus is defined as the relatively stable fraction of organic matter that is left after most of the plant and animal residues have been decomposed (Brady & Weil 2002). A healthy soil has a great number of bacteria present, about 10-50 million per 5 g of soil. Moulds and other microorganisms should also be present (Schroeder & Sprague 1994). Bacteria and fungi which, are mainly saprophytic (feed off dead organic matter) are two important groups in the soil system (Roux 1969). The living fraction of the soil is invaluable in making the soil a favourable place for plants to grow (Schroeder & Sprague 1994). This is relevant in mine rehabilitation, because the capping soil which has been stockpiled has its normal biological processes disturbed. This results in the decline in the abundance of microbes and mycorrhizal spores, which leads to a decrease in nutrient mineralization and an increase in denitrification (Fresquez & Lindemann 1982).

Soil pH is closely linked to creating a favourable environment for microbes. Jackson (1993) commented that since pH affects the availability of all plant nutrients, it therefore also directly affects plant establishment, growth, and development. This is partially due to microorganisms that make nutrients available to the plants because they require a particular optimal pH (Jackson 1993). Nitrogen-fixing microbes are quite specific about their pH preference (Jackson 1993). Tate (1995) states that that in general the host plant is less sensitive to low soil pH than the Rhizobium species. The host may grow at a pH as low as 4, while the bacterial symbiant require a soil pH greater that 5 to survive. There are four major groups of N-fixing bacteria found in rood nodules, *Rhizobium*, *Bradyrhizobium*, *Sinorhizobium* and *Azorhizobium* (Young & Haukka 1996).

Microorganisms compete constantly for assimilates but due to their ability to break down organic matter (Roux 1969), they play key roles in many of the nutrient cycles that need to occur in order for plants to grow. An example of one of these cycles is the nitrogen cycle. If the soil becomes waterlogged and poorly aerated, then N can be lost to the atmosphere during decomposition, while N is also lost through leaching (Schroeder & Sprague 1994). Fresh supplies of soil minerals are also released by microbial action on silt and clay particles. It is convenient therefore that soil conditions that promote plant growth are the same that encourage a healthy soil microorganism population (Schroeder & Sprague 1994).

Soil microbes, along with making nutrients available to plants, also aid in the aeration of the soil by the process of granulation (Jackson 1993). Brady & Weil (2002) define granulation as the process of forming soil aggregation. The depth to which granulation occurs depends on the quality and quantity of the soil microbes, and the type of compounds microbes make available to the plants (Jackson 1993).

At Frankenwald, the University of the Witwatersrand (WITS) research farm, two Honours studies were undertaken to investigate fungi in the Transvaal Highveld climax grassland ("Purple veld"). Paterson (1949) found that certain fungi were present in all plots exposed to different burning and grazing treatments, while the occurrence of other fungi was treatment-specific. Kessel (1965) found that when investigating *Cynodon*, *Eragrostis*, *Hyparrhenia* and "Purple veld", "Purple veld" had the least number of fungal colonies (130) while *Eragrostis* had the most (316). Although Roux (1969) expressed concerns about the exact values of the results because of the methods used, the results are interesting.

Grasslands sites in Canada and the USA have been examined for soil microorganisms. Parkinson & Bhatt (1974) examined a site (Matador) in Canada and found that in the top 30 cm of soil six fungi were dominant: *Trichoderma* spp., *Fusarium* spp., *Penicillium* spp., sterile dark forms and *Paecilomyces* spp., while Christensen & Scarborough (1989) found that 17% of the species isolated from Pawnee (USA) were *Fusarium*. Two of the dominant bacterial species found at these sites were *Arthrobacteria* and *Bacillus* (Lowe & Paul 1974; Paul *et al.* 1979). However, according to Paul *et al.* (1979), it is important to realise that microorganisms in grasslands vary greatly in function and morphology, and their interactions between each other and their environment are extremely complex.

2.5.3. Organic matter

Organic matter is the remainder or residue of dead plants and animals (Jackson 1993). Favourable weather and climatic conditions, plus soil microorganisms, result in the decomposition of organic matter on land. Humus is normally dark in colour, and is the relatively stable portion of soil organic matter that is left after the majority of organic matter has been decomposed (Brady & Weil 2002). Humic substances influence the soil microbial populations by means of the carbon cycle (Jackson 1993). Carbon is the microbes food source, therefore it would follow that the amount of C in the soil influences the microbial soil populations. Fresquez & Lindemann (1982) indicate that an available source of carbon is vital in stimulating and activating soil microflora.

When soils consist of mainly small particles, e.g., clay and silt, then poor drainage is often a problem. This poor drainage could result in compacted layers forming when there is heavy traffic on the wet soils. These compacted layers cause problems for plant root growth. The application of lime and peat or humus in the topsoil, will create an open structure in the soil, which is more conductive for grass root growth. Grass roots themselves also improve the soil up to the depth to which they grow, by adding to the soil organic matter when they die. When the roots die and are converted to humus, this organic product act as binding agents in the soil which improves its structure. An improvement in the structure aids in soil aeration. Sandy soils have the best soil aeration but the lowest moisture holding capacity and nutrient supplying power (Schroeder & Sprague 1994).

Tiny particles of humus and clay (<0.002 mm) are called colloids and they have an important role to play in the plant available nutrients in the soil. Colloids have large surface areas because they are so small and they are electrically charged (mainly negatively). This negative charge allows the colloids to attract and hold positively charged ions called cations e.g., Ca^{2+}, Mg^{2+}, K^+, Na^+, $NH_4^+$and H^+. Due to this, colloids can store certain plant available forms of plant nutrients and prevents them from being leached. The amount of negative charge on the colloids in a specific mass of soil is referred to as the soil's cation exchange capacity (CEC). Good soils in South Africa have CECs of 5-20 cmol (+) kg^{-1}, while poorer soils have lower CECs (Miles & Manson 2000).

A variety of methods are used in agriculture to increase the soil organic matter. One of these is to plough in organic material, e.g., manure, straw and a growing crop (green manure crop). Some of the advantages of using a green manure cover crop, apart from its role in increasing organic matter, are that it covers the soil which protects the soil from direct raindrop impact thus preventing erosion, and it retains mobile nutrients during the rainy season. However, after the organic matter has been ploughed into the soil, a period of reduced available soil nitrogen occurs because the soil microbe populations increase dramatically and so use the available N and other inorganic nutrients while decomposing the organic matter. The duration of this nitrogen deficient period can last from two weeks to six months, depending on the quality of the organic matter and soil temperature and moisture. If a young nitrogen-high crop was used, decomposition would be rapid and thus nitrates and ammonium compounds would be available within a short period of time. However, it is important that sufficient water is available during the decomposition. Sufficient water is also required if the main crop, which is planted after the cover crop, is to reap the benefits of the increased soil organic matter (Malherbe 1953).

2.5.4. Sewage sludge

It was found by Topper & Sabey (1986) that western USA coal mines often use inorganic fertilizer to promote rapid growth of plant cover for rehabilitation of mine dumps, while organic ameliorants are not widely used. However an organic ameliorant, e.g. sewage sludge, might be preferable to inorganic fertilizers when revegetating the coal mine's disturbed areas (Topper & Sabey 1986). This is because firstly, sewage sludge releases nitrogen slowly, over 3-5 years (Sopper & Seaker 1983). Secondly, it improves the soil's physical properties, by increasing the soil organic matter and water holding capacity (Hinesly *et al.* 1982). And thirdly, sludge stimulates microbial activity by creating a favourable environment for microbial activity because sludge is a carbon source for microbes (Fresquez & Lindemann 1982). Due to these advantages, it is therefore perhaps not surprising that when comparing sludge with additions of inorganic N and P fertilizer, a sludge level of 83 t ha^{-1} resulted in a greater plant growth for two growing seasons (Topper & Sabey 1986). This yield included the seeded grasses and forbs (Topper & Sabey 1986). It was also found that the lower levels of sludge application (14 t ha^{-1}) had higher concentrations of seeded grass growth when compared to the high sludge applications. From these experiments it was suggested that an application rate of 15 t ha^{-1} of sewage sludge was most beneficial for grass growth, even when compared to its inorganic fertilizer equivalent. However, when calculating the theoretical quantities of plant available N and P, in all the treatments the levels of P in the sewage sludge were comparable to their inorganic fertilizer equivalent, but only the14 t ha^{-1} sludge treatment had N levels within the inorganic fertilizer range (Topper & Sabey 1986). Pietz *et al.* (1989b) showed that it was also possible to establish a grass-lucerne (*Medicago sativa* (L.)) mixture on acidic coal refuse material, when applying sludge. However, the highest dry matter yield was obtained from a sewage sludge and lime treatment (Pietz *et al.* 1989a).

One of the possible problems with sewage sludge is that it lowers the pH of the spoil possibly because of nitrification and the production of organic acids (Miller 1974). However, Lejcher & Kunkle (1973) found that acidic spoil could be raised from a pH of 2.8 to 6.2 when digested sludge was applied. This was thought to be due to sludge's buffering ability (Peterson & Gschwind 1972). A further constraint is that sewage sludge is very variable, even if it is from the same source. Sopper & Kerr (1982) said that stabilized sewage sludge could be used for the revegetation of coal mines, with no adverse effects to the environment and little or no risk to animal or human health.

2.5.5. Humate

K-humate is a manufactured concentrated soil conditioner that contains a complex of organic matter derived from plants and coal, called humates (Omnia 2002). K-humate was incorporated into mine soil rehabilitation the trials as a soil ameliorant due to the manufacturers and distributors (Omnia) claims that it is beneficial for plant growth.

Humates possess physical and chemical properties essential to the fertility of all types of soil. Humates are also referred to as humic acids. Humic and fulvic (fulvates) acids are organic molecules formed by the decomposition of plant matter. Humic acids are larger in size than fulvic acids, and are therefore more stable. Humic acids will eventually be broken down into fulvic acids, so humates last longer and are more effective. Humates have two important chemical groups: carboxylic and phenolic acid groups. These groups are effective in chelating with most plant nutrients (Omnia 2002). Chelating is when an organic molecule is bonded tightly to a metallic ion by multiple chemical bonds (Brady & Weil 2002).

It is claimed by the Omnia that K-humate increases soil productivity and fertility by the prevention of soil crusting, improving nutrient penetration and retention in the soil, stabilizing the soil pH fluctuations from fertilizer applications, and stimulating microbial activity. These are according Omnia (2002) achieved in various ways.

Firstly, Omnia (2002) say that humates improve the soil's ability to retain nutrients (especially sandy soils). This is because, by adding humate, the concentrations of carboxylic and phenolic acid groups in the soil are increased. When applied, the humate coats the soil particles or get trapped in cracks and pores. The carboxylic and phenolic acid groups in the humate are negatively charged and therefore hold most of the elements, e.g., nitrogen, potassium, calcium, magnesium and trace elements (from applied fertilizers). Humates also improve the soil water retention. This is achieved because the humates hinder water from escaping through the soil's cracks and pores. Secondly, humates reduce soil compaction, which is a major problem in heavy clayey soils. These soils tend to be either waterlogged or hard and cracked. K-humate improves these soils by interacting with the clay particles, and preventing them from flocculating (sticking together) when the soil dries out. This is achieved when the large humate molecules are able to keep the clay particles apart. In so doing it allows for water and nutrients to penetrate the clay and thus prevent shrinking. Thirdly K-humate is said to reduce soil acidity by acting as a buffer.

This buffering ability aids in the reduction of soil acidity caused when Ca, Mg, Zn, Cu, Fe and Mn (Manganese) are exchanged for H ions by the plant roots, during nutrient uptake (Omnia 2002). Although Omnia (2002) claim that K- humate stimulates microbial activity, Fresquez & Lindemann (1982) suggested that a fresh source of carbon (i.e., sewage sludge) was needed to stimulate microbial populations in coal spoil, even though humic materials were present. This was because microbes do not readily oxidize humic materials (Fresquez & Lindemann 1982; Brady & Weil 2002).

Humic substances have been tested but the scientific integrity of the data needs to be questioned, as the results are mainly expressed as generalised trends, as is shown by the following humate experiments. Lee & Bartlett (1976) tested the stimulation of maize and algae growth by humic substances. They found that when applying the humic acid to soil that was low in organic matter or had low nutrient levels, the greatest growth response was evident. On soil that had high organic matter content, a small or even slightly negative response was seen. The optimum level of humic acid for maize stimulation was 5 ppm C (carbon) as Na-humate.

The growth actually decreased at high levels of 50 ppm when compared to 5 ppm C as Na-humate. Lee & Bartlett (1976) said that it was unlikely that the increase in growth was due to any additional nutrients present in Na-humate, because these amounts were minimal when compared to the nutrients available in the soil. De Kock (1955) found that when applying 20 ppm C as Na-humate as a foliar spray to maize, the yield increased about 20%.

Farina & Brockett (nd.a) tested three humic products. These were Omniboost, Omnispoor and K-humate. These products are designed to increase the availability of nutrients in the soil (K-humate) and or enhance the nutrient supply (Omniboost and Omnispoor). There have been both successes and failures in trying to prove the advantages of these products. Unfortunately according to Farina & Brockett (nd. a), most experiments have been done in greenhouses or are non-statistical field experiments.

Gypsum, Omnispoor and K-humate was tested on a maize farm in Kamberg valley, KwaZulu-Natal (KZN). On heavy clay soils, the products were applied at three levels; gypsum (0, 200 and 400 kg ha^{-1}), Omnispoor (0, 3 and 6 kg ha^{-1}) and K-humate (0, 20 and 40 kg ha^{-1}) were tested. The treatments did not have any beneficial effect on the maize yields in the Kamberg valley (Farina & Brockett nd.a). It is not ideal to extrapolate results from limited research data, therefore another experiment was conducted in KZN in the Cedarville (dryland) and Dundee areas (irrigated), on maize farms with sandy soils. The treatments were Omnispoor (0, 3 and 6 kg ha^{-1}), Omniboost (0, 3 and 6 kg ha^{-1}) and K-humate (0, 20 and 40 kg ha^{-1}). Again the humic acid products did not have any beneficial effect on the maize growth (Farina & Brockett nd.b). In summary, the value of humic acid products remains dubious.

2.5.6. Fly ash

Fly ash is a by-product of coal combustion, and consists of tiny glass-like particles (Carlson & Adriano 1993; Gupta *et al.* 2002). It is one of many Coal Combustion Products (CCPs), which are formed when burning either hard or brown coal (WCI 2003b). Consumption of South African coal yields between 20%-30% fly ash, and an estimate of 25 Mt annum^{-1} is produced by South African power stations (Hodgson & Krantz 1995). Prior to 1985 fly ash was disposed of by wet methods, e.g., ash dams, but now dry methods have been implemented (van den Berg *et al.* 2001). It has been found by monitoring studies that pollutants from the fly ash dams do not migrate readily, due to the site-specific conditions, but the ground water was found to be polluted, mainly by sodium and sulphate (Hodgson 1987). Generally dry disposal methods reduce the possibility of ground water pollution (Roger & Kean 1980).

One of the possibly useful aspects of fly ash is that it affects the physiochemical characteristics of soil, because it is usually very basic. Adriano *et al.* (1980) showed that fly ash raised the pH of soil ameliorated with weathered fly ash from <6.0 to ≈8.0 and unweathered ash from <6.0 to ≈12. Fly ash also contains various essential and non-essential elements, but is poor in available phosphorus and nitrogen (Table 2.2). However, according to Gupta *et al.* (2002) fly ash is potentially useful in agriculture as a fertilizer or soil ameliorant. Fail & Wochok (1977) showed that plants in fly ash treated transects had about a nine times greater total dry weight than those in the control (transects not treated with fly ash), and that there was an average increase of twelve times the number of root nodule formations on the fly ash treated soybeans compared to the control. These results could to be due to the correction of micronutrient deficiencies. ERRI (1995, 1996, and 1997) said that beneficial trace elements were found on the surface of the ash particles, but the trace metals seem to be immobile due to the basic nature of the fly ash. Unfortunately due to the basic nature of the fly ash B, As and Se^{+} do tend to be mobile (ERRI 1995, 1996,1997). Some fly ashes have very high levels of micronutrients e.g., B (450 ppm), Mn (200 ppm), Zn (90 ppm), Cu (40 ppm) and Mo (20 ppm) (Capp & Engle 1967; Adams *et al.* 1972). But according to Kovacic & Hardy 1972 and Fail & Wochok 1977, due to the soil pH neutralizing ability of fly ash, the toxicity of Al^{3+}, Mn^{2+} and other metallic ions could be prevented (Kovacic & Hardy 1972; Fail & Wochok 1977).

Table 2.2: Nutrient composition of fly ash from a Vereeniging power station (Plant laboratory at Cedara, KwaZulu-Natal Department of Agriculture and Environmental Affairs).

N	Ca	K	P	Mg	Na	Zn	Cu	Mn
%	%	%	%	%	mg. kg^{-1}	mg. kg^{-1}	mg. kg^{-1}	mg. kg^{-1}
0.49	0.74	0.10	0.24	0.08	200.6	108.0	154.9	96.0

Conversion is % x 10 000 = mg. kg^{-1}

A characteristic that needs to be taken into account is the variability of fly ash. The variability is due to a number of reasons such as differences in the parent material, the emission control equipment and the way it is stored and handled (Adriano & Weber 2001). An example of this variability is the fly ash base potential, which changes from power station to station (van den Berg *et al.* 2001), therefore the liming ability of each batch needs to be established if it is to be used as a liming agent.

2.5.7. Legumes

In South Africa about 50 annual and perennial pasture legumes are used to improve grazing. This is because South Africa's soil and climatic conditions vary a great deal (Wassermann *et al.* 2000). Farmers may use single-stand legumes as a forage crop, but legumes are also planted in combination with grasses. Most of these grass-legume pastures are based on cool-season species. There are various benefits to establishing grass and legumes together in a pasture. Firstly, by planting legumes, the quantity of inorganic nitrogen fertilizer is reduced, which reduces costs (Lyle 1987; Aucamp 2000). Legumes transfer their nitrogen to the grass via dung and urine from grazing animals and plant matter decomposition. The decay of legume root nodules is another way nitrogen is made available to the grass. Legumes can supply 50 to 300kg N ha^{-1} $annum^{-1}$ to the system. Secondly, by planting legumes with grass, the vulnerability of the pasture from adverse conditions of pests, diseases, soil conditions and adverse weather is spread (Donaldson 2001). This is because if there are different species present, there is a greater chance that some of them will survive the disturbance better than others, because of greater tolerance levels for pests, drought or soil condition.

When deciding to plant a grass-legume pasture, it is advisable to select a soil type or fertilize to suit the legume. The ratio for grass-legume pasture is usually two-thirds grass and one-third legume (Donaldson 2001). Although this is not easy to maintain, the pasture can be managed in order to promote one or the other component (Bartholomew 2000; Donaldson 2001). To reduce the presence of the legumes, nitrogen fertilizer can be applied at about 100 kg N ha^{-1} per season. To increase the legume, for example clover, optimum levels of K and P are required along with a rest after heavy grazing (Donaldson 2001). Barnes *et al.* (1986) reviewed various legume veld reinforcement trials, which consisted of 17 legume species, and different potential management objectives. It was found that only crown vetch (*Coronilla varia* (L.)) (Vegetation management guidelines 2003) persisted, and in fact tended to take over, which was not necessarily desirable. It was, however, also slow to establish and the soil needed a high level of lime and phosphate.

For legumes to be a success in a grass-legume pasture the following conditions need to apply: adequate P needs to be present in the soil; the appropriate *Rhizobium*, *Bradyrhizobium*, *Sinorhizobium* or *Azorhizobium* needs to be used when inoculating the legume; the legume needs to be planted with a grass that will not dominate it, for example a fast growing ryegrass; they must not be overgrazed before they have been properly established and; sufficient water needs to be available to the legumes (Donaldson 2001).

Legumes have the ability to use chemically inactive atmospheric dinitrogen, due to N-fixing *Rhizobium* species that form nodules on the legume roots. These bacteria are aerobic, Gram-negative and non-spore forming soil bacteria (Van Egeraat 1975). Most soils have indigenous rhizobial strains and legumes are generally specific about the species and strain of *Rhizobium* they hold. For example lucerne requires *S. meliloti*, while clovers need *R. trifolii* to fix nitrogen (Allen & Allen 1981).

Nitrogen-fixing bacteria start to multiply when they come into contact with the host seedling root exudates. They enter the root via the root hair. Once they have achieved this, they infect the root cortex and stimulate cell division, forming a root nodule. This nodule formation takes about three to four weeks (Allen & Allen 1981). Nodules containing active rhizobial bacteria are pink to red in colour, while non-active nodules are transparent (Wassermann *et al.* 2000).

The advantages of having legumes in combination with grass is that they increase the soil nitrogen and improve animal production (Donaldson 2001), but the disadvantages are also notable, such as a change in the grass species composition to less desirable species (Barnes *et al.* 1986). The need for efficient management is essential as the requirement of the legumes and the grasses need to be balanced. According to Barnes *et al.* (1986) in the case of veld reinforcement the use of legumes does not appear to be justified.

2.6. DISCUSSION

The soil environment is a highly complex system, which comprises of a multitude of components and component interactions. These components not only vary from place to place, but also at different depths. Due to this variability it is necessary to limit the aspects investigated to specific parameters, for example, soil compaction, acidity and low nutrient levels. However, when investigating these problems it is necessary to remember that they are not isolated, therefore possible solutions often affect more than one aspect of the soil.

Table 2.1: Summary of selected soil problems and solutions experienced during mine rehabilitation.

	Problems		
Solutions	Compaction	Acidity	Low Nutrients
Fertilizer			x[1]
Legumes	x[16]	x[14]	x[14, 15]
Lime		x[1,13,20]	x[2, 13]
Microbes	x[2]		x[1,2,3]
Fly ash		x[11,18,19]	x[12,17]
Humate	x[4]	x[4]	x[4]
Organic matter e.g. sewage sludge	x[1,4,6]	x[7,9,10]	x[1,5,8]

1. Schroeder & Sprague (1994)
2. Jackson (1993)
3. Roux (1969)
4. Omnia (2002)
5. Sopper & Seaker (1983)
6. Hinesly *et al.* (1982)
7. Pietz *et al.* (1989a)
8. Topper & Sabey (1986)
9. Lejcher & Kunkel (1973)
10. Peterson & Gschwind (1972)
11. Hodgson (1990)
12. Gupta *et al.* (2002)
13. Miles & Manson (2002)
14. Donaldson (2001)
15. Van Egeraat (1975)
16. Chancellor (1977)
17. Adriano *et al.* (1980)
18. Fail & Wochok (1977)
19. Kovacic & Hardy (1977)
20. Brady & Weil (2002)

One of the initial aims of land rehabilitation is to get plants to grow (WCI 2003a). Once plants are able to grow, and growth is sustainable, hopefully the soils' natural cycles will return, and a healthy soil system should slowly emerge from the relatively dead soil system caused by open cast coal mining.

Soil ameliorants do not necessarily affect only one aspect of the soil. This can be seen in humate, organic matter, lime, fly ash, legumes and microbes (Table 2.1), which all alleviate more than one of the negative conditions which occur in soil after mining. Unfortunately, these soil ameliorants can also cause certain problems, e.g., fertilizer tends to promote undesirable grass species composition (Barnes *et al.* 1986). Fertilizer, when compared with the other soil ameliorants (Table 2.1), also seems to only improve nutrient availability, while sewage sludge improves all three problems. It would therefore seem logical to apply sewage sludge when rehabilitating, rather than fertilizer. However, this currently does not happen, as mines tend to use fertilizer (Topper & Sabey 1986). The reasons for using fertilizer rather than sewage sludge are likely to be economical and/or logistical, since fertilizer is readily obtainable, transportable, and known to promote speedy plant growth.

When considering soil ameliorants for the rehabilitation process, it is necessary to understand the ecological systems involved. For instance, soil microbes are essential in breaking down organic matter and thus releasing nutrients into the soil (Schroeder & Sprague 1994). Questions that could be asked are: whether it is necessary to add microbes to the soil. Whether the appropriate microbes occur there naturally. Whether they will arrive anyway once the conditions are favourable, since conditions that promote plant growth are also preferable for soil microorganisms (Schroeder & Sprague 1994). It was also noted in Paterson (1949) that some fungi appeared to be treatment specific in grassland, while Kessel (1965) also found that under different grasslands the soil fungi varied. It was found by Fresquez & Lindemann (1982) that microorganism invaded coal spoil from surrounding areas, it was however not possible to say whether they were important in aiding the rehabilitation process.

The use of legumes in rehabilitation could possibly have two beneficial effects. Firstly, as a rooted plant, it would help reduce soil compaction (Chancellor 1977). This would occur when the roots decay, and this would increase the amount of organic matter in the soil. Schroeder & Sprague (1994) noted that increasing soil organic matter increases the amount of humus, which improves the soil's structure. Secondly, legumes contain N-fixing *Bradyrhizobium* in root nodules (Allen & Allen 1981). Due to these rhizobia, the legumes can convert unusable atmospheric N_2 to plant-usable N (Van Egeraat 1975). The N present in legumes can also be used by surrounding plants once the plant has been decomposed or eaten, and transferred to other plants via dung or urine (Donaldson 2001). Unfortunately, legumes such as lucerne require different management compared to grass and in the case of veld reinforcement, it does not appear feasible to use legumes (Barnes *et al.* 1986).

A point that must be kept in mind is that problems are often area specific, and Farina & Brockett (nd. b) advise not to extrapolate results from one area to another. However, if an area has low soil organic matter content, in order for the system to be sustainable organic matter needs to be increased. One of the faster ways of doing this is to incorporate sewage sludge.

This can be done together with lime if soil acidity is a problem. Fly ash has also been said to be effective (Hodgson 1990), but fly ashes liming ability and metal element composition need to be measured before use. Inorganic fertilizers are probably always going to be used to a certain extent in mine rehabilitation, because they promote speedy plant growth (Topper & Sabey 1986), which is an important step in rehabilitating an area. However, in the long term, they are not as effective as sewage sludge (Sopper & Seaker 1983) despite the fact that they are cheaper to transport and easier to apply. Another aspect is that, by using sewage sludge and fly ash, waste products are being effectively and usefully disposed of.

2.7. CONCLUSION

There appear to be several ways of rehabilitating soil after mining has occurred, and the use of sewage sludge seems to be one of the most effective (Sopper & Seaker 1983). Using one soil ameliorant is unlikely to be an effective 'quick fix' solution to the rehabilitation of 'dead soil', in a system where one problem leads to another. However, mines are businesses and require the rehabilitation process to be as efficient, compliant and as cost effective as possible.

3. General description of the Witbank area

3.1. AREA DESCRIPTION

Optimum Mine (26° 0' 20.04" S, 29° 36' 45.24" E) and Syferfontein Mine (26° 24' 2.22" S, 29° 13' 13.90" E) are situated in the Mpumalanga province, South Africa, with Witbank being the largest town in the region. The area is primarily used for coal mining, beef farming and maize farming. It is classified under Acocks (1975) as Veld Type 61, Bankenveld, which is false grassland. Rutherford & Westfall (1986) also classify it as grassland. The topography is gently undulating, with pans often present in the lower lying areas. According to Rutherford & Westfall (1986) the vegetation in the grassland biome is mainly determined by rainfall. Areas with above 625 mm annum^{-1} rainfall are classified as sour veld, dominated by sour grasses (Rutherford & Westfall 1986). This is because, the higher rainfall in these areas, tend to leach soils so they become dystrophic (Rutherford & Westfall 1986). Although the rainfall is slightly lower than would be expected (approximately 590 mm annum^{-1}), leaching does occur because the soils are, according to Rutherford & Westfall (1986), free draining. This area is classified as a summer rainfall area. The average annual maximum and minimum temperatures in this area are about 22.8°C and 7.9 °C.

3.2. SOIL

The soil group accounting for 50% of the Grassland Biome is the red-yellow-grey latosol plinthic catenas, which tend to be acidic (Rutherford & Westfall 1986). These soils are accompanied by red and black solonetzic soils and black freely drained latosol clay soils. The latosol clay soils are generally only found in the Grassland Biome (Rutherford & Westfall 1986). According to Rutherford & Westfall (1986), erosion in this biome is only a problem in the higher rainfall areas when the vegetation has been severely depleted.

3.2.1. Optimum Mine soil

Before mining commenced the following soil forms were identified: Hutton (Hu), Avelon (Av), Clovelly (Cv), Glenrosa (Gs), Westleigh (We), Glencoe (Gc), Fernwood (Fw), Kroonstad (Kd), and Katspruit (Ka). For most of these soils the required rehabilitation topsoil depth is 300 mm, according to the Institute of Pedological Research (IPR 1984).

3.2.2. Syferfontein Mine soil

At Syferfontein Mine, there were 22 soil forms identified, in an Environmental Impact Assessment (EIA) done before mining commenced. These included: Valsrivier (Va), Bonheim (Bo), Oakleaf (Oa), Swartlands (Sw), Avalon (Av), Kroonstad (Kd), Longlands (Lo), Mayo (My), Clovelly (Cv), Willowbrook (Wo), Inhoek (Ik), Hutton (Hu), Steendal (Sn), Arcadia (Ar), Rensburg (Rg), Westleigh (We) and Mispah (Ms). The most common soils are Clovelly, Rensburg and Avalon respectively (Loxton, Venn & Associates 1989).

Soils on the alluvial plains were deep and dark in colour (e.g., Oakleaf). Most of them were heavy in texture. Examples of these were Valsrivier, Bonheim, Willowbrook and Arcadia. They varied due to differences in surface structure, expansion ability and wetness. In the upland areas black clay soils were found. A few examples are the Arcadia soils which tended to have a good nutrient status but were strongly expansive and drained poorly. Swartland and Mayo soil forms were lighter in colour and unstructured with a high clay content. Although the drainage in Swartland and Mayo is better than Arcadia, the erosion potential is high. Red and yellow soils were also found, but most still had a high clay content (Loxton, Venn & Associates 1989).

3.3. GRASS SPECIES COMPOSITION SURVEY

A limited vegetation survey was undertaken on the 20th and 21st of January 2003, with the aim to determine the species composition. The mines holdings surveyed in the Witbank area were Kromdraai Mine (25° 45' 27.6"S, 29° 0.5' 48.1" E), Optimum Mine and Syferfontein Mine. All three mines are open cast coal/ strip mines. Two grasslands were surveyed on each of the mines holdings using the step point method (Mentis 1981). The first grassland was undisturbed while the second had been rehabilitated about five years previously.

3.3.1. Rehabilitated sites

The rehabilitated areas have been managed in various ways. At Kromdraai Mine, once the spoil has been covered with capping soil, agricultural lime (5 t ha^{-1}), and 2:3:2 (N: P: K) fertilizer (1 t ha^{-1}) and superphosphate (10.5%) (1 t ha^{-1}) was applied, and after 3 months 0.5 t ha^{-1} of limestone ammonium nitrate (LAN (28%)). After five years no more fertilizer was applied. The area was also burnt every four years and mown every year. At Syferfontein Mine, the rehabilitated area was treated with 0.1 t LAN (28%) ha $annum^{-1}$ for two years. It was also mown and grazed when required, while at Optimum Mine, fertilizers were applied for about three years. Various grass seed mixes were used at all the mines to reseed the areas to be rehabilitated (Table 3.1). According to Dixon & Meney (1994) reseeding is the most cost effective and efficient way of revegetating a large degraded area with a diverse range of plant species.

3.3.1.1 Results

From the survey the total number of species present at the various rehabilitated sites did not vary a great deal. Only grass species were recognised for this survey, although lucerne was included, as Kromdraai Mine used it for rehabilitation. On Optimum Mine 13 spp. were found, at Syferfontein Mine eight spp. and Kromdraai Mine eight spp. (Table 3.1). While commencing the survey it was observed that certain species were dominant. At Optimum Mine the most dominant species were seen to be *Digitaria eriantha*, *Eragrostis curvula* and *Cynodon dactylon*, while at Syferfontein Mine, *E. curvula* and *D. eriantha* tended to dominate. At Kromdraai, *D. eriantha* was found to be extremely dominant, while the lucerne was almost absent from the system.

3.3.2. Undisturbed sites

Due to this area being used extensively for agriculture it was not always possible to survey undisturbed grassland near the mines in question. This was the case at Optimum Mine, so a near-by area was sampled that was relatively undisturbed, i.e., had not been cultivated for a number of years. The species that were found in this survey were compared to a veld condition survey done in the south-eastern Transvaal by Rethman & Kotzé (1986).

3.3.1.2 Results

It was found that Syferfontein Mine had the greatest number of species with 27, followed by Kromdraai with 24, and finally Optimum Mine with 22 (Table 3.2). When compared to the veld condition survey, Syferfontein Mine had approximately 66%, Optimum Mine had approximately 59% and Kromdraai approximately 54% of the grass species found by Rethman & Kotzé (1986). Many of the species tended to be increaser II's (Table 3.2), but these are not necessarily unfavourable, e.g., *E. curvula* which is considered to have a high grazing value (van Oudtshoorn 1999). Along with this a few decreaser species were found; most importantly for this study was *T. triandra* at the Syferfontein and Kromdraai mines (Table 3.2).

3.4. DISCUSSION

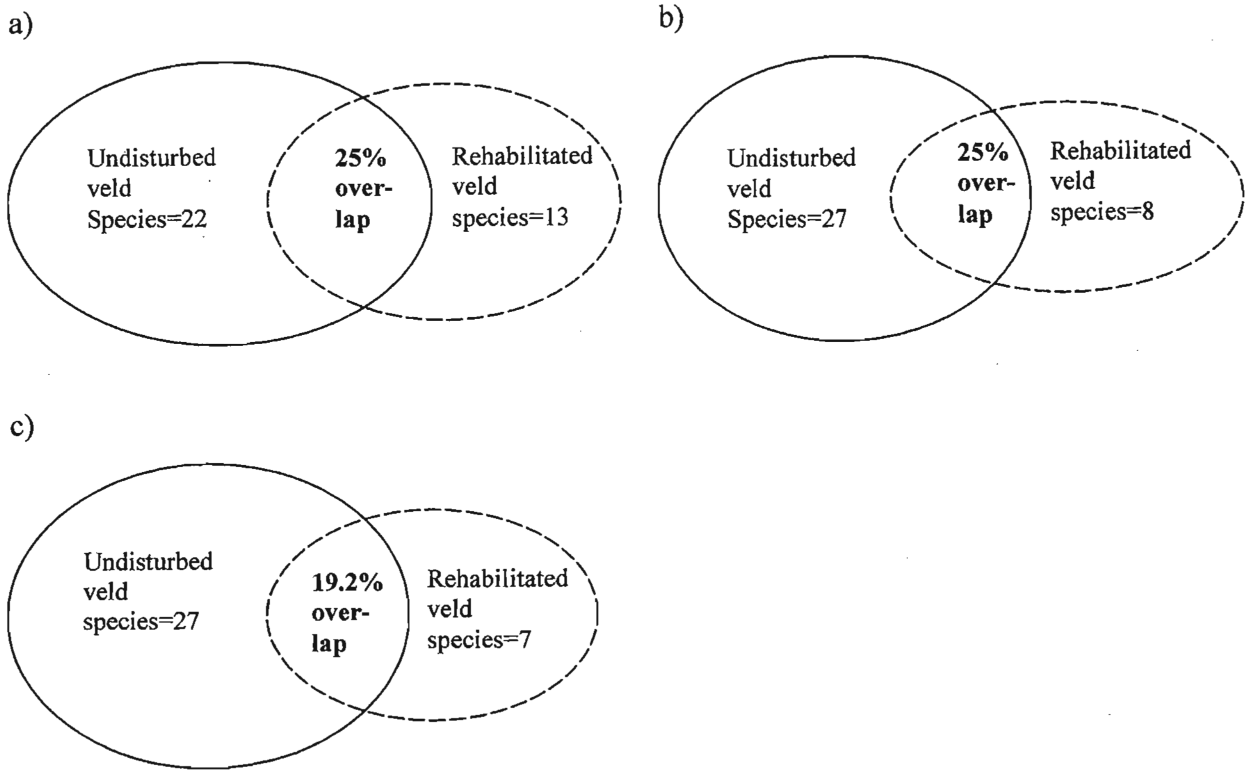

Figure 3.1: The number of grass species found and species percentage overlap, in undisturbed veld and rehabilitated veld at a) Optimum Mine, b) Syferfontein Mine and c) Kromdraai Mine.

When comparing the species found in the rehabilitated sites with the undisturbed areas, it was found that Optimum Mine and Syferfontein Mine both had a 25% overlap, while Kromdraai had about a 19.2% overlap. The majority of the species found were in the undisturbed areas. In the rehabilitated areas, even though fewer species were found, more were present than were originally planted (Table 3.1), which was encouraging in terms of species richness. What was not encouraging was the dominance of one or two species, namely *D. eriantha* and *E. curvula.* Barnes *et al.* (1986) found that *Eragrostis* spp., especially *E. curvula*, tended to dominate in grassland once it was fertilized with N and P fertilizers. Fynn and O' Connor (in press) also found that *E. curvula*, a tall narrow-leaved species, and *Panicum maximum*, a tall broad-leaved species, were the only species that did not decrease in abundance when nitrogen fertilizers only was applied. They also found that tall broad-leaved species dominated where neither N nor P were limiting. These were also the most productive sites (Fynn & O'Connor in press). This would account for the dominance of *D. eriantha*, which is a tall broad-leaved grass. The dominance of *E. curvula* and *D. eriantha* will change in time if the management practices change. The application of fertilizers will either have to be reduced or stopped, in order for a greater species richness to exist, since Fynn & O'Connor (nd.) have shown, that as the level of N increases so species richness (grasses and forbs) decreases. These changes will have to occur in order for the grasslands to be properly rehabilitated to their original states.

The mined areas were surveyed about five years after rehabilitation measures had been undertaken, so it was probable that sufficient time had not elapsed since fertilization was stopped, for the effects to be noticed in the species composition. Although soil pH was not recorded during the survey, it was measured at various times from different topsoil stockpiles from Optimum Mine and Syferfontein Mine, and these were generally found to be acidic (Chapters 5, 6 and 7). This is of importance because *E. curvula* and *Tristachya leucothrix* appear to be more abundant if the soil has a low pH, and their abundance is reduced when lime is added (Fynn & O'Connor in press). The converse is true for *Heteropogon contortus*, *Setaria nigrirostis*, *Cymbopogon excavatus* and *Hyparrhenia hirta*, which increased in abundance when lime was added with fertilizer (Fynn & O'Connor in press). These species were found in the undisturbed grassland (Table 3.2), which could indicate a higher soil pH than in the rehabilitated areas. This would suggest that a greater amount of lime should also be applied on the rehabilitated sites, along with a reduction in fertilizer applications, if species richness is to be improved.

3.5. CONCLUSION

When assessing the rehabilitated sites, it would be necessary to conduct further surveys of the areas. This would allow for sufficient time to elapse, for the effect of the cessation of fertilizer applications to be evident. This is necessary as, although revegetation has occurred, the rehabilitated sites have been found to be lacking species, when compared to the undisturbed areas species richness. The effect of time on the population dynamics would also be beneficial to study in these areas, as it could be used to predict the trends on rehabilitated areas.

Table 3.1: Grass species and lucerne composition of rehabilitated areas on three open cast coal mines, and the original seeds planted.

Spp.	Optimum Mine		Syferfontein Mine		Kromdraai Mine	
No.	Species recorded after 5 years	Species of seeds planted	Species recorded after 5 years	Species of seeds planted	Species recorded after 5 years	Species of seeds planted
1	*Andropogon eucomus*	*Digitaria eriantha*	*Digitaria eriantha*	*Chloris gayana*	*Chloris gayana*	*Chloris gayana*
2	*Chloris gayana*	*Eragrostis teff*	*Themeda triandra*	*Digitaria eriantha*	*Cynodon dactylon*	*Digitaria eriantha*
3	*Cymbopogon excavatus*	*Chloris gayana*	*Chloris gayana*	OR	*Digitaria eriantha*	*Eragrostis teff*
4	*Cynodon dactylon*		*Setaria sphacelata*	*Eragrostis curvula*	*Eragrostis curvula*	*Medicago sativa*
5	*Digitaria eriantha*		*Paspalum distichum*	*Eragrostis teff*	*Eragrostis gummiflua*	
6	*Eragrostis curvula*		*Hyparrhenia hirta*		*Hyparrhenia hirta*	
7	*Eragrostis gummiflua*		*Eragrostis curvula*		*Melinis repens*	
8	*Eragrostis racemosa*		*Paspalum urvillei*		*Medicago sativa*	
9	*Heteropogon contortus*					
10	*Panicum schinzii*					
11	*Pennisetum clandestinum*					
12	*Pogonarthria squarrosa*					
13	*Themeda triandra*					

Table 3.2: Grass species composition and species categories for undisturbed areas on three open cast coal mines, compared to a veld condition survey done in the South-eastern Transvaal (Rethman & Kotzè 1986).

	Syferfontein Mine		Kromdraai Mine		Optimum Mine		Veld condition	
No.	Category	Species	Category	Species	Category	species	Category	Species
1	inc 2	*Aristida congesta*	inc 2	*Aristida congesta*	inc 2	*Aristida congesta*	dec	*Themeda triandra*
2	dec	*Brachiaria serrata*	inc 2	*Aristida diffusa*	inc 3	*Aristida junciformis*	dec	*Monocymbium ceresiiforme*
3	inc 1	*Cymbopogon validus*	inc 1	*Cymbopogon excavatus*	inc 2	*Aristida obtusa*	inc 1	*Hyparrhenia hirta*
4	inc 1	*Cymbopogon excavatus*	dec	*Digitaria eriantha*	inc 2	*Cynodon dactylon*	dec	*Diheteropogon amplectencs*
5	inc 2	*Cynodon dactylon*	dec	*Diheteropogon amplectens*	dec	*Digitaria eriantha*	p	*Eulalia villosa*
6	dec	*Digitaria eriantha*	dec	*Elionurus muticus*	dec	*Diheteropogon amplectens*	inc 2	*Digitaria tricholaenoides*
7	inc 3	*Elionurus muticus*	inc 2	*Eragrostis capensis*	inc 2	*Elionurus muticus*	p	*Paspalum spp*
8	inc 2	*Eragrostis capensis*	inc 2	*Eragrostis chloromelas*	inc 2	*Eragrostis capensis*	p	*Setaria spp*
9	inc 2	*Eragrostis curvula*	inc 2	*Eragrostis curvula*	inc 2	*Eragrostis curvula*	invas	*Pennisetum clandestinum*
10	inc 2	*Eragrostis gummiflua*	inc 2	*Eragrostis gummiflua*	inc 2	*Eragrostis gummiflua*	inc 1	*Tristachya leucothrix*
11	inc 2	*Eragrostis plana*	inc 2	*Eragrostis nindensis*	inc 2	*Eragrostis racemosa*	inc 2	*Heteropogon contortus*
12	inc 2	*Eragrostis racemosa*	inc 2	*Eragrostis racemosa*	invas	*Eragrostis teff*	inc 1	*Alloteropsis semialata*
13	inc 1	*Harpochloa falx*	inc 2	*Heteropogon contortus*	inc 2	*Heteropogon contortus*	dec	*Brachiaria serrata*
14	dec	*Helictotrichon turgidulum*	inc 1	*Hyparrhenia hirta*	inc 1	*Hyparrhenia hirta*	inc 1	*Trachypogon spicatus*
15	inc 2	*Heteropogon contortus*	inc 1	*Melinis nerviglumis*	inc 1	*Melinis nerviglumis*	lg	*Stiburus conrathii*
16	inc 1	*Hyparrhenia hirta*	inc 2	*Melinis repens*	inc 2	*Monocymbium ceresiiforme*	inc 1	*Harpochloa flax*
17	inc 2	*Microchloa caffra*	inc 2	*Monocymbium ceresiiforme*	?	*Panicum sp.*	inc 3	*Elionurus muticus*
18	invas	*Paspalum paspalodes*	inc 2	*Panicum schinzii*	inc 2	*Pogonarthria squarrosa*	inc 2	*Eragrostis curvula*
19	invas	*Paspalum urvillei*	inc 2	*Pogonarthria squarrosa*	?	*Sporobolus sp.*	inc 2	*Eragrostis plana*
20	?	*Setaria nigrirostris*	dec	*Setaria sphacelata*	inc 2	*Tragus berteronianus*	inc 2	*Eragrostis racemosa*
21	inc 2	*Setaria pallide-fusca*	inc 2	*Sporobolus nitens*	inc 2	*Trichoneura grandiglumis*	inc 2	*Eragrostis capensis*
22	dec	*Setaria sphacelata*	dec	*Themeda triandra*	inc 1	*Tristachya leucothrix*	?	*Eragrostis spp*
23	inc 2	*Sporobolus nitens*	inc 2	*Tragus berteronianus*			inc 3	*Rendlia altera*
24	dec	*Themeda triandra*	inc 1	*Tristachya leucothrix*			inc 2	*Loudetia simplex*
25	inc 2	*Tragus berteronianus*					inc 2	*Panicum natalense*
26	inc 2	*Trichoneura grandiglumis*					up	*Aristida spp*
27	inc 1	*Tristachya leucothrix*						

Grazing status categories were assigned, if they were not present then grazing values were used (van Oudtshoorn 1999) or Rethman & Kotzè's (1986) grouping.

dec = Decreaser species, decrease in number as the veld deteriorates.

inc 1= Increaser I species, increase when veld in underutilised.

inc 2= Increaser II species, increase when veld in overgrazed.

inc 3= Increaser III species, unpalatable species abundant in overgrazed veld.

invas= Invaders species, are not indigenous to the area, mostly pioneers.

p= palatable species.

lg= low grazing value species.

up= unpalatable species.

?= if specie was not classified in either text or was unknown.

4. Evaluation of soil ameliorants for the growth of *Themeda triandra* on landfill soil in KwaZulu-Natal, South Africa

4.1. INTRODUCTION

Landfills create a major ecological disturbance, and it is therefore necessary to rehabilitate these areas. Umlazi Landfill in KwaZulu-Natal, South Africa is one such example and is characterised by red, generally acidic soils, which are not suitable for optimal grass growth. This study was conducted in order to investigate soil ameliorants, which would improve indigenous grass growth, and thus aid in the area's rehabilitation. As this area should ultimately be able to be used as a rangeland, *Themeda triandra* was used. *Themeda triandra* is a palatable grazing grass and is an indicator of rangeland in good condition (van Oudtshoorn 1999).

Various soil ameliorants, e.g., sewage sludge and fertilizer, have been used in soil rehabilitation studies. Seaker & Sopper (1998) found that a disturbed ecosystem's recovery tended to be accelerated when sewage sludge was used, compared to when inorganic fertilizer was applied. Topper & Sabey (1986) also indicated that when organic fertilizer was applied, microbial activity was increased which increased nutrient availability in the soil. Lime has also been tested along with sewage sludge as a soil ameliorant and was found to be effective in establishing plant growth in acidic conditions (Pietz *et al.* 1989b). Microbes have been noted to be beneficial to plant growth as was shown in a study done by Ugoji *et al.* (2002) that showed *Bacillus* species having a positive effect of growth stimulation in *Zea mays*. The soil ameliorant, K-humate, was included in this study because humic substances are said to produce optimum plant growth when combined with the other mineral requirement of the plant (Kline &Wilson 1994).

This study focussed specifically on the use of macro fertilizer nutrients (N, P and K), sewage sludge (dried), microbes (a combination of *Trichoderma harzianum* and a *Bacillus* *subtilis* Strain 69), K-humate (liquid humus) and lime (dolomitic) as possible soil ameliorants for the rehabilitation of the Umlazi Landfill soil.

4.2. MATERIALS AND METHODS

4.2.1. Site description of Umlazi Landfill

Soil used in the study was delivered from Umlazi Landfill in Durban, South Africa (29°59’00’’S; 30°45’30’’E). Before the landfill was excavated, 200 mm of topsoil was removed and stored for the final capping. The landfill site has a gradient of approximately 1:2 slope, and is classified as an H: h, which means that certain hazardous wastes can be dumped there. It was capped with various layers, the first being 300 mm ash or 153 mm stone. Thereafter a geofabric A5 (Bidim) was placed over the ash, and geofabric A2 over the stone. Layers of clay (total of 450 mm) were then applied followed by a capping of 200 mm of topsoil.

4.2.2. Method

Two soil samples were obtained from Umlazi landfill (topsoil and subsoil). This soil was used instead of mine capping soil, which was not available at the time. Both soils were analysed (Table 4.1) at the Soil Fertility and Analytical Services Laboratory (KwaZulu-Natal Department of Agriculture and Environmental Affairs, Cedara) (hereafter referred to as Cedara) using techniques described by Hunter (1975) and Farina (1981).

Table 4.1: Analysis of soil obtained from Umlazi Landfill site

Soil ID	P	K	Ca	Mg	Exch. Acidity	Total cations	Acid sat.	pH (KCl)	Zn	Mn	NIRS organic carbon	NIRS clay
	mg/L	mg/L	mg/L	mg/L	cmol/L	cmol/L	%		mg/L	mg/L	%	%
Topsoil	1	89	900	333	0.06	7.52	1	6.78	1.6	1	1.2	19
Subsoil	1	73	150	65	1.04	2.15	41	3.88	1.2	11	<0.5	38

The experiment was carried out in 200 mm diameter (approximate volume 3000 mL) pots in a greenhouse at the University of KwaZulu-Natal, Pietermaritzburg. The minimum and maximum temperature in the greenhouse were 2 °C and 42 °C. The experimental design was a 2^6 factorial (Randomised Complete Block Design), with three replications (Fig. 4.1). All treatments were applied at two levels, none and optimal. A single five-week-old *Themeda triandra* seedling (plug) was planted in each pot. The *T. triandra* plugs were grown from seed at TopCrop Superlawn Nursery facilities. They were grown in composted pine bark with urea and lime (Seedling growth medium (SMG)). One ton of SMG contains 4 kg of urea and 4 kg lime and once a week hydroponic nutrient powder (6.5 %N, 2.7 %P, 13 %K, 7 %Ca, 2.2 %Mg, 7.5 %S, 0.15 %Fe, 0.024 %Mn, 0.024 %B, 0.005 %Zn, 0.002 %Cu and 0.001 %Mo) was added to the seedling (the grass plugs for all the trials adhered to these specifications). The pots were watered to field capacity. This was done on a weight basis. However, as the grass seedlings grew, this method became less and less accurate, as the plants required more water than was allocated.

4.2.3. Nitrogen application

Nitrogen was applied in the form of LAN (28% N). It was applied at three intervals over the experiment. The first application of 50 kg N ha^{-1} was applied before the plugs were planted, while the second and third applications of 60 kg N ha^{-1} were each applied at four-week intervals. These application rates were for both top and subsoil. The rates were calculated per pot, (based on surface area of pot) (Appendix 1).

4.2.4. Phosphorus application

Phosphorus was applied as single super phosphate (10.5% P). It was applied at 65 kg P ha^{-1} before the plugs were planted for both top and subsoil. The application rate was calculated per pot (Appendix 2).

4.2.5. Potassium application

Potassium was applied in the form of KCl (50% K). It was applied before the plugs were planted. The topsoil had a recommended application rate of 80 kg ha^{-1} and the subsoil 120 kg ha^{-1}. The rates were calculated per pot (Appendix 3).

4.2.6. Sewage sludge application

Dried sewage sludge from the Ixopo Sewage Works, KwaZulu-Natal was used. Since P was the soils most limiting nutrient, the sludge application rate was calculated to fulfil the P recommended rates, 65 kg ha^{-1}, which calculates to 5.8 t sludge ha^{-1} (Appendix 4).

4.2.7. Microbe application

Two microbes were used, *Trichoderma harzianum* (EcoT[1]) a fungus, and *Bacillus subtilis* Strain 69 (B69), a bacterium. The microbe treatment consisted of a combination of *T. harzianum* ($5x10^8$ spores gm^{-1}) and a *B. subtilis* Strain 69 ($1x10^9$ c.f.u). One gram of each stock culture was diluted in 1.0 L of water. The mixture was mixed and 43 mL pot^{-1} of mixture was applied after planting and then at 4-week intervals. A new mixture was prepared for each application from the same stock cultures.

4.2.8. K-humate application

The recommended application rate of K-humate was 10 L ha^{-1}, therefore the humate was diluted at 1: 200 water and 0.0314 mL pot^{-1} was applied to each pot. Humate was applied after planting and at 4-week intervals.

4.2.9. Lime application

Dolomitic agricultural lime was applied on the top- subsoil at 3 t ha^{-1}. The application rates were greater than the rates recommended by Cedara (0 and 1 t.ha^{-1} respectively), this was done to ensure a reaction. The per pot quantities were calculated (Appendix 5), and were applied before planting.

The measurements taken after 11 weeks of growth were the above ground biomass and below ground biomass. Total plant biomass and the above ground to below ground ratio (A: B ratio) were calculated. As the data for all parameters were not normally distributed, they

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[1] EcoT® is registered under Act 36 of 1947 with The South African registrar of Agricultural Remedies.

were log-transformed, to meet the assumptions of the ANOVA. In the results only up to the third order interactions were taken into account. Non-significant mean and interaction tables were put into the appendices: above ground main effects (Appendix 6), above ground biomass two-way interactions (Appendix 7), below ground biomass main effects (Appendix 8), below ground biomass two-way interactions (Appendix 9), total biomass main effects (Appendix 10), total biomass two-way interactions (Appendix 11), A: B ratio main effects (Appendix 12) and A: B ratio two-way interactions (Appendix 13).

Figure 4.1: Randomised Complete Block Design layout for the Umlazi Landfill Trial, run in the greenhouse at the University of KwaZulu-Natal

4.3. RESULTS

Table 4.2: Analysis of variance table for *Themeda triandra* (log g pot^{-1}) on Umlazi top and subsoil with various soil ameliorants. The ANOVA was cut off at the 3-way interaction level, P= 0.05, significant effects in bold.

		Above biomass		Below biomass		Total biomass		Above: Below ratio	
S.O.V	d.f	v.r	F pr.	v.r	F pr.	v.r	F pr.	v.r	F pr.
Rep	2	5.32		1.42		13.89		8.54	
Fertilizer	1	123.09	**<.001***	23.27	**<.001***	112.97	**<.001***	13.95	**<.001***
Humate	1	0.00	0.993^{NS}	0.09	0761^{NS}	0.01	0.941^{NS}	0.08	0.771^{NS}
Lime	1	1.14	0.289^{NS}	9.13	**0.003***	4.82	**0.030***	4.11	**0.045***
Microbes	1	0.53	0.470^{NS}	3.03	0.0.084^{NS}	2.40	0.124^{NS}	1.17	0.282^{NS}
Sludge	1	169.46	**<.001***	47.90	**<.001***	174.57	**<.001***	10.30	**0.002***
Soil	1	0.57	0.452^{NS}	4.05	**0.046***	0.20	0.653^{NS}	5.87	**0.017***
Fertilizer.Humate	1	0.13	0.721^{NS}	0.45	0.503^{NS}	0.00	0.990^{NS}	0.78	0.378^{NS}
Fertilizer.Lime	1	0.08	0.781^{NS}	0.02	0.895^{NS}	0.00	0.972^{NS}	0.11	0.745^{NS}
Humate.Lime	1	0.99	0.320^{NS}	0.05	0.816^{NS}	0.78	0.379^{NS}	0.28	0.598^{NS}
Fertilizer.Microbes	1	0.76	0.385^{NS}	0.11	0.744^{NS}	0.01	0.917^{NS}	0.90	0.345^{NS}
Humate.Microbes	1	0.12	0.728^{NS}	0.63	0.427^{NS}	0.11	0.739^{NS}	1.00	0.320^{NS}
Lime.Microbes	1	6.12	**0.015***	0.47	0.495^{NS}	2.99	0.086^{NS}	1.44	0.232^{NS}
Fertilizer.Sludge	1	97.12	**<.001***	29.78	**<.001***	98.02	**<.001***	4.97	**0.028***
Humate.Sludge	1	0.24	0.622^{NS}	0.95	0.332^{NS}	0.69	0.409^{NS}	0.30	0.584^{NS}
Lime.Sludge	1	0.38	0.540^{NS}	0.24	0.622^{NS}	0.24	0.623^{NS}	0.82	0.368^{NS}
Microbes.Sludge	1	1.87	0.174^{NS}	0.00	0.982^{NS}	0.74	0.393^{NS}	0.97	0.326^{NS}
Fertilizer.Soil	1	17.68	**<.001***	6.69	**0.011***	16.61	**<.001***	0.51	0.477^{NS}
Humate.Soil	1	0.17	0.679^{NS}	0.04	0.849^{NS}	0.58	0.447^{NS}	0.02	0.901^{NS}
Lime.Soil	1	1.30	0.257^{NS}	6.64	**0.011***	0.62	0.431^{NS}	10.43	**0.002***
Microbes.Soil	1	0.14	0.710^{NS}	1.77	0.186^{NS}	0.41	0.523^{NS}	2.28	0.134^{NS}
Sludge.Soil	1	0.04	0.836^{NS}	1.07	0.303^{NS}	1.06	0.306^{NS}	0.65	0.423^{NS}
Fertilizer.Humate.Lime	1	0.07	0.788^{NS}	0.31	0.576^{NS}	0.03	0.871^{NS}	0.53	0.469^{NS}
Fertilizer.Humate.Microbes	1	1.54	0.217^{NS}	0.75	0.387^{NS}	2.68	0.104^{NS}	0.01	0.912^{NS}
Fertilizer.Lime.Microbes	1	4.73	**0.032***	0.05	0.395^{NS}	3.27	0.073^{NS}	0.68	0.412^{NS}
Humate.Lime.Microbes	1	0.05	0.825^{NS}	0.03	0.548^{NS}	0.05	0.825^{NS}	0.16	0.692^{NS}
Fertilizer.Humate.Sludge	1	0.01	0.928^{NS}	0.04	0.445^{NS}	0.20	0.654^{NS}	0.41	0.522^{NS}
Fertilizer.Lime.Sludge	1	2.65	0.106^{NS}	0.00	0.875^{NS}	1.93	0.168^{NS}	1.12	0.292^{NS}
Humate.Lime.Sludge	1	1.46	0.230^{NS}	0.05	0.417^{NS}	1.22	0.271^{NS}	0.02	0.883^{NS}
Fertilizer.Microbes.Sludge	1	0.01	0.934^{NS}	0.50	0.483^{NS}	0.07	0.788^{NS}	0.51	0.477^{NS}

Table 4.2 (continue overleaf)

		Above biomass		Below biomass		Total biomass		Above: Below ratio	
S.O.V	d.f	v.r	F pr.	v.r	F pr.	v.r	F pr.	v.r	F pr.
Humate.Microbes.Sludge	1	0.05	0.820^{NS}	2.56	0.112^{NS}	0.10	0.748^{NS}	2.70	0.103^{NS}
Lime.Microbes.Sludge	1	3.24	0.074^{NS}	0.01	0.927^{NS}	1.57	0.213^{NS}	1.55	0.215^{NS}
Fertilizer.Humate.Soil	1	0.06	0.804^{NS}	0.00	0.961^{NS}	0.13	0.717^{NS}	0.05	0.817^{NS}
Fertilizer.Lime.Soil	1	0.08	0.776^{NS}	0.98	0.323^{NS}	0.83	0.365^{NS}	0.51	0.476^{NS}
Humate.Lime.Soil	1	0.05	0.825^{NS}	0.31	0.580^{NS}	0.08	0.775^{NS}	0.13	0.723^{NS}
Fertilizer.Microbes.Soil	1	0.07	0.790^{NS}	0.77	0.383^{NS}	0.00	0.989^{NS}	1.01	0.317^{NS}
Humate.Microbes.Soil	1	0.70	0.406^{NS}	0.26	0.613^{NS}	0.12	0.729^{NS}	1.18	0.279^{NS}
Lime.Microbes.Soil	1	0.35	0.558^{NS}	0.10	0.749^{NS}	0.02	0.887^{NS}	0.55	0.460^{NS}
Fertilizer.Sludge.Soil	1	6.90	**0.010***	5.74	**0.018***	8.15	**0.005***	0.08	0.777^{NS}
Humate.Sludge.Soil	1	0.48	0.491^{NS}	0.29	0.594^{NS}	0.96	0.330^{NS}	0.00	0.987^{NS}
Lime.Sludge.Soil	1	0.47	0.492^{NS}	0.14	0.709^{NS}	0.12	0.726^{NS}	0.74	0.390^{NS}
Microbes.Sludge.Soil	1	0.07	0.791^{NS}	0.81	0.369^{NS}	0.70	0.406^{NS}	0.41	0.525^{NS}
Residual	126								
Total	191								
cv%		22.2		34.0		14.9		167.0	

NS=non-significant; * = $P< 0.05$

Table 4.3: Response of *Themeda triandra* above ground biomass (log g pot^{-1}) to applications of fertilizer, sludge and microbes to top- and subsoil.

a)

	Microbes		
Lime	Without	With	Means
Without	1.01a	0.95ab	0.98
With	0.90b	1.00a	0.95
Means	0.96	0.98	

b)

	Sludge		
Fertilizer	Without	With	Means
Without	0.44c	1.15ab	0.80
With	1.09b	1.18a	1.14
Means	0.77	1.17	

c)

	Soil		Means
Fertilizer	Sub	Top	
Without	0.72d	0.87c	0.80
With	1.19a	1.08b	1.14
Means	0.95	0.98	

Values with letters in common are not significantly different P=0.05
$LSD_{P=0.05}$ marginal means=0.06
$LSD_{P=0.05}$ body of table= 0.09

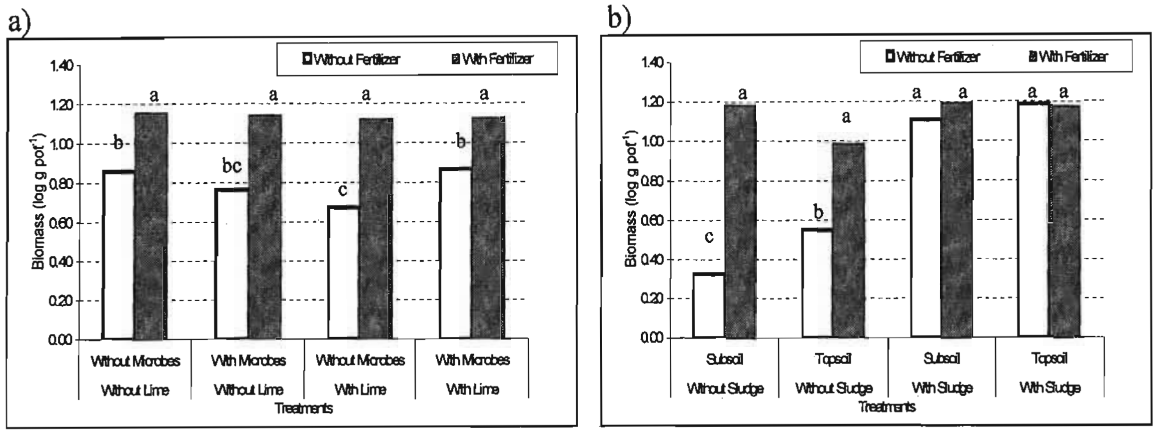

Figure 4.2: Means for *Themeda triandra* above ground biomass (log g pot^{-1}) three-way interactions. If bars have letters associated with them, then only letters that differ indicate significant differences, while bars with letters in common indicate no significant difference, P= 0.05.

Table 4.4: Response of *Themeda triandra* below ground biomass (log g pot^{-1}) to applications of fertilizer, sludge and lime on the top- and subsoil.

a)

	Sludge		
Fertilizer	Without	With	Means
Without	0.46b	0.94a	0.70
With	0.86a	0.91a	0.89
Means	0.66	0.93	

b)

	Soil		
Fertilizer	Sub	Top	Means
Without	0.69c	0.71bc	0.70
With	0.97a	0.80b	0.92
Means	0.83	0.80	

c)

	Soil		
Lime	Sub	Top	Means
Without	0.838a	0.860a	0.85
With	0.821a	0.643b	0.73
Means	0.83	0.75	

Values with letters in common are not significantly different P=0.05
$LSD_{P=0.05}$ marginal means=0.08
$LSD_{P=0.05}$ body of table= 0.11

a)

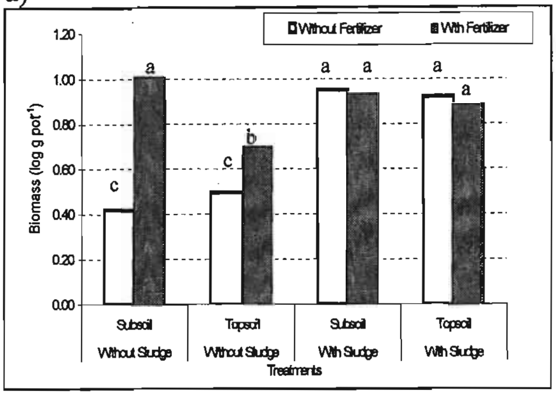

Figure 4.3: Means for *Themeda triandra* below ground biomass (log g pot^{-1}) three-way interactions. If bars have letters associated with them, then only letters that differ indicate significant differences, while bars with letters in common indicate no significant difference, P= 0.05.

Table 4.5: Response of *Themeda triandra* total biomass (log g pot^{-1}) to applications of lime.

a)

Lime	
Without	With
1.24a	1.18b

Different letters indicate a significantly different P=0.05
LSD$_{P=0.05}$= 0.05

Table 4.6: Response of *Themeda triandra* total biomass (log g pot^{-1}), to applications of fertilizer and sludge on top- and subsoil.

a)

	Sludge		
Fertilizer	Without	With	Means
Without	0.78c	1.37ab	1.08
With	1.31b	1.39a	1.35
Means	1.05	1.38	

b)

	Soil		
Sludge	Sub	Top	Means
Without	1.06b	1.02b	1.04
With	1.38a	1.39a	1.39
Means	1.22	1.21	

Values with letters in common are not significantly different P=0.05
LSD$_{P=0.05}$ marginal means=0.05
LSD$_{P=0.05}$ body of table= 0.07

a)

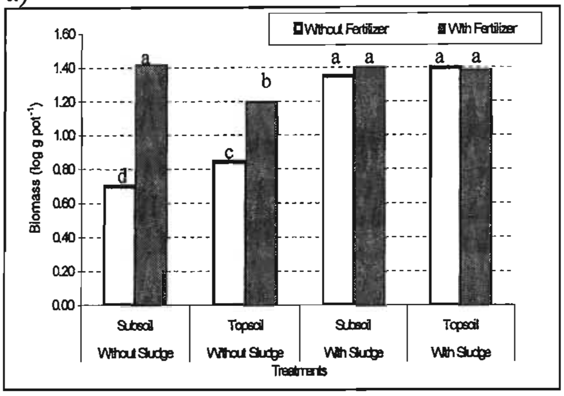

Figure 4.4: Means for *Themeda triandra* total biomass (log g pot^{-1}) three-way interactions. If bars have letters associated with them, then only letters that differ indicate significant differences, while bars with letters in common indicate no significant difference, P= 0.05.

Table 4.7: Response of *Themeda triandra* above ground: below ground biomass to applications of fertilizer, sludge, and lime to top- and subsoil.

a)

	Sludge		
Fertilizer	Without	With	Means
Without	0.02b	0.21a	0.12
With	0.23a	0.28a	0.25
Means	0.13	0.24	

b)

	Soil		
Lime	Sub	Top	Means
Without	0.15b	0.11b	0.13
With	0.98b	0.33a	0.66
Means	0.57	0.22	

Values with letters in common are not significantly different P=0.05
$LSD_{P=0.05}$ marginal means=0.12
$LSD_{P=0.05}$ body of table= 0.08

4.3.1. Results summary

- In above ground biomass, the main effect of fertilizer and sludge were significant ($P<0.001$), along with the fertilizer and sludge interactions ($P<0.001$). However, these must be seen in relation to the fertilizer, sludge and soil interactions that were significant ($P=0.01$) (Fig. 4.2b). This is because the effects of fertilizer and sludge on the above ground biomass of *T. triandra,* depended on the soil type (top- or subsoil).
- Fertilizer, lime and microbes interactions had a significance of $P=0.032$. The positive effect of fertilizer on the above ground biomass was not negated by the addition of lime or microbes. However, without the addition of fertilizer, lime appeared to have a significantly negative effect on the above ground biomass. The addition of microbes significantly improved the yield when lime was added (Fig.4.1c).
- In the below ground biomass, fertilizer, sludge and soil interactions were once again significant ($P=0.018$). Therefore the soil type needs to be taken into consideration when discussing the positive effect of fertilizer and sludge on below ground biomass.
- Lime and soil interactions were interesting because lime significantly reduced below ground biomass only when applied to the topsoil (Table 4.4c), which has an acid saturation of 1% ($P=0.011$).
- The interaction between fertilizer and sludge indicates that either could be used to improve the above ground, below ground and total biomass of the *T. triandra*.
- Fertilizer, sludge and soil interactions were again significant ($P=0.005$) as are fertilizer and soil ($P<0.001$) and fertilizer and sludge ($P<0.001$).
- Above ground: below ground ratios (A: B ratios) revealed that fertilizer and sludge were significant ($P=0.028$). The control (no treatment) had a significantly lower A: B ratio than when fertilizer and/or sludge were added. Therefore, sludge and fertilizer promote above ground growth.
- In the lime and soil interactions, lime, when applied to topsoil, resulted in a significantly higher A: B ratio ($P=0.002$). This was probably due to lime's negative

effect on the lower ground biomass rather that its promotion of above ground biomass growth.

- Humate was the only soil ameliorant that did not have any effect on plant growth.

4.4. DISCUSSION

The most important interactions for above ground biomass were the fertilizer, sludge and soil interactions and the fertilizer, lime and microbe interactions. In the initial reaction, it was interesting to discover that the subsoil, once it had been ameliorated with fertilizer or sludge, produced higher above ground biomass yields than the topsoil (Fig. 4.2b). This is probably due to the subsoil's high clay content, which would aid in water and nutrient retention. We can see from the two-way interactions of fertilizer and soil (Table 4.3c) that fertilizer significantly increased the above ground yield of *T. triandra* by 9% more in the subsoil than the topsoil. In the fertilizer, lime and microbe interactions (Fig. 4.2a) it was surprising to note that the lime had a negative effect on above ground biomass and that microbes significantly alleviated some of the negative effects caused by the lime. Above ground biomass was 11% lower than when microbes were not added (Table 4.3a). This could be due to a slight increase in acidity that would be caused from microbial mineralization and the subsequent the release of NH_4^+ (Miles & Manson 2000). Therefore *T. triandra* appears to prefer acid soil conditions. Fertilizer and sludge were seen to be exchangeable as both significantly increased the above ground yield ($P<0.001$). They both significantly improved plant growth, probably because they alleviated the soil nutrient deficiencies, specifically P.

As in the above ground biomass, fertilizer, sludge and soil are significant ($P=0.018$) in the below ground biomass. The lime and soil interactions unexpectedly showed that topsoil was negatively affected by the application of lime. The lime treatment significantly decreased below ground biomass of the topsoil by 22% compared to the subsoil (Table 4.4b). The lime is thought to not have had any effect on the subsoil, which was more acidic than the topsoil. As was expected from the above ground biomass results, fertilizer significantly increased below ground biomass of the subsoil compared to the topsoil.

The fertilizer, sludge and soil interactions were found to be significantly different (P=0.01). This is useful to know because if there is insufficient topsoil to rehabilitate Umlazi Landfill, then subsoil can be used to cap the landfill. Initially the subsoil capping will require more fertilizer, to increase its nutrient value to recommended levels. Once it has been fertilized the subsoil will produce greater yields than the topsoil. Even though these results showed that fertilizer and sludge can both be used to increase the nutrient levels of the soil, according to Seaker & Sopper (1998), there should be a greater benefit to the ecosystem in the long term if sewage sludge is used because it improves the soil structure and soil microbe activity. In the fertilizer, lime and microbe interactions, we can observe that the use of lime when growing *T. triandra* does not appear to be advisable as it decreased total biomass. Although the microbes alleviated this negative effect, this trial did not supply enough detail to be definitive.

The lime and soil interaction of the above ground biomass was significant (P=0.002). No significant results were achieved in the above ground biomass when lime was added to the topsoil but it significantly reduced the below ground biomass, we can therefore assume that the topsoil was over limed and this inhibited root growth. This was probably the cause of the higher above ground: below ground biomass ratio.

5. The application of three soil microbes on mine capping soils when growing *Themeda triandra* and *Cynodon dactylon*

5.1. INTRODUCTION

Soil microorganisms play key roles in many of the soil nutrient cycles (Schroeder & Sprague 1994). These microbes do this by breaking down organic matter, in their continual competition for food (Roux 1969). Most of the biological transformations occur in the rhizosphere (Fuhrman & Azam 1982), which is the portion of soil surrounding the plant roots, in which most bacterial growth is stimulated (Elsas *et al.* 1997). This is due to the release of hormones and vitamins by the roots, which promote bacterial and fungal growth (Mokolobate 2000).

One of the main nutrient cycles microbes participate in is the carbon cycle (Brock & Madigan 1991). Microbes use the energy in the C-H bonds to initiate many of the other nutrient cycles (Brock & Madigan 1991). The major source of carbon (C) is found in soil organic matter, which is about 50% C (Jackson 1993). Another important cycle is the nitrogen cycle. Since N is one of soil's most frequently limiting nutrients in terms of plant growth (Brock & Madigan 1991), it would therefore, only be of benefit to promote microbes that can turn non-plant usable N_2 into plant usable ammonium (NH_4^-) and nitrate (NO_3^-) (Mokolobate 2000).

Another way in which certain microbes are able to promote plant growth is by the moderation of various soil borne diseases. An example of such a soil microbe, in this case a fungus, is *Trichoderma harzianum* (Health Canada Pest Management Regulatory Agency 2002), while certain soil *Bacillus* spp. are also known to induce toxicity symptoms in house fly (*Musca domestica*) larva (Shakoori *et al.* 1998). Studies have also shown that *Trichoderma* spp. (Parkinson & Bhatt 1974) and *Bacillus* spp. (Harris 1971; Lowe & Paul 1974) were found in grassland soil. Certain microbes also form symbiotic relationships with plants, thus aiding in the acquisition of soil nutrients. Lee (1997) showed that certain symbiotic fungal root relationships of vesicular-arbuscular mycorrhiza (VAM's) had positive effects on grass plant growth.

It is therefore fortunate that the soil conditions that promote plant growth also encourage healthy soil microorganism populations (Schroeder & Sprague 1994). The aim of this study was therefore, to determine whether selected soil microbes affected the growth of *Themeda triandra* and *Cynodon dactylon* in mine capping soil.

5.2. MATERIALS AND METHODS

Microbe trials were conducted in the Grassland Science greenhouse at the University of KwaZulu-Natal, Pietermaritzburg. The soil used was collected from Optimum Mine and Syferfontein Mine in Mpumalanga (Chapter 3.2). The soil was crushed to break down any large soil aggregates that may have been present. Plastic bags were placed in the 200 mm diameter pots to negate the leaching of nutrients. The pots were filled with soil to about 20 mm below the rim the soil weight (air dried) was about 3 kg pot^{-1}.

The experiment consisted of four pot trials, two on Optimum Mine soil and two on Syferfontein Mine soil, each trial had three soil microorganisms treatments, *Trichoderma harzianum* (EcoT), *Bacillus subtilis* Strain 69 and 77 (B69 and B77). The trials were, M1 (Optimum Mine soil growing *Themeda triandra*), M2 (Optimum Mine soil growing *Cynodon dactylon*), M3 (Syferfontein Mine soil growing *T. triandra*) and M4 (Syferfontein Mine soil growing *C. dactylon*). The grass species used were *T. triandra*, these seedlings (plugs) were grown from seeds collected in the Ermelo district, Mpumalanga and *C. dactylon* 'Seagreen'. Each pot trial was a 2^3 factorial with four replications in a Randomised Complete Block Design (RCBD).

Each soil was analysed at Cedara using techniques described by Hunter (1975) and Farina (1981). Four soils were deficient in P and K (Table 5.1). The two Optimum Mine soils were mixed, as were the two Syferfontein soils, this was to ensure sufficient soil for the trials. Dried sewage sludge from the Ixopo Sewage Works, KwaZulu-Natal, was used to improve the soils' nutrient levels. Sludge was used because it was also a source of carbon for the microbes. Since P was found to be the limiting factor, the amount of sewage sludge added per pot was calculated for the required level of P (Appendix 4). Both soils required 65 kg P ha^{-1}. The sewage sludge was mixed into the pot soil before planting. Lime was also applied to Optimum Mine soil trials at 3 t ha^{-1} (Appendix 5).

Table 5.1: Analysis of soil obtained from Optimum Mine and Syferfontein Mine used as capping soil

Soil ID	P	K	Ca	Mg	Exch. Acidity	Total cations	Acid sat.	pH (KCl)	Zn	Mn	NIRS Organic carbon	NIRS clay
	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	Cmol L^{-1}	Cmol L^{-1}	%		mg/L	mg/L	%	%
Optimum 1	3	40	264	78	0.03	2.09	1	4.46	0.2	2	<0.5	59
Optimum 2	2	55	108	41	0.95	1.97	48	4.18	0.1	2	<0.5	43
Syferfontein 1	3	244	1828	756	0.03	16.05	0	6.25	0.8	1	2.7	45
Syferfontein 2	3	194	2049	874	0.04	17.95	0	6.74	0.6	1	2.4	40

The concentration of the EcoT fungal inoculation was approximately 5×10^{8} spores g m^{-1} and for *Bacillus* 69 and 77, 1×10^{9} c.f.u. (1g L^{-1}). These were applied at 43 mL pot^{-1}, at the beginning of the experiment and thereafter at 4-week intervals.

The pots were watered with tap water to soil field capacity. However, due to the changing water requirement of the plants as they grew, it was found to be more suitable to water as required.

The trials, M1, M2, M3 and M4 were harvested after 9, 11, 11 and 11 weeks respectively. The discrepancy in plant growth time was permissible, as the treatment results from the four trials were not compared to each other. The above and below ground biomass was harvested, and dried at 60°C. Roots were washed out with water in a sieve with an aperture of 2mm. After drying at 60°C, the roots and above ground foliage were weighed and the total dry biomass and above ground: below ground ratio (A: B ratio) was calculated, the data was analysed using analysis of variance (ANOVA), and significant differences assessed at the 5% significance level. When comparing the control (no treatments) with treatments in the third order interactions, Bonferroni adjusted LSDs for multiple comparisons were used. Only significant means tables were presented in the text, non-significant tables were put into

Appendices: Non-significant M1 mean main effect tables (Appendix 14), M1 two-way interactions (Appendix 15), M2 mean main effect tables (Appendix 16), M2 two-way interactions (Appendix 17), M3 mean main effect tables (Appendix 18), M3 two-way interactions (Appendix 19), M4 mean main effect tables (Appendix 20) and M4 two-way interactions (Appendix 21).

5.3. RESULTS

Table 5.2: Analysis of variance for *Themeda triandra* biomass (g pot^{-1}) on Optimum Mine soil, using three soil microorganisms (trial M1), P= 0.05, significant effects in bold.

		Above biomass		Below biomass		Total biomass		Above: Below ratio	
S.O.V	d.f	v.r	F pr.	v.r	F pr.	v.r	F pr.	v.r	F pr.
Rep	3	1.40		1.23		1.23		22.42	
B69	1	0.04	0.85^{NS}	0.94	0.342^{NS}	0.52	0.477^{NS}	1.00	0.328^{NS}
B77	1	0.04	0.846^{NS}	0.69	0.414^{NS}	0.40	0.532^{NS}	1.92	0.181^{NS}
EcoT	1	0.80	0.381^{NS}	0.72	0.407^{NS}	0.03	0.873^{NS}	2.53	0.127^{NS}
B69.B77	1	1.71	0.205^{NS}	1.11	0.304^{NS}	0.01	0.909^{NS}	4.76	**0.041***
B69.EcoT	1	0.90	0.352^{NS}	0.37	0.549^{NS}	0.00	0.984^{NS}	3.65	0.07^{NS}
B77.EcoT	1	6.61	**0.018***	0.37	0.548^{NS}	2.37	0.139^{NS}	1.62	0.217^{NS}
B69.B77.EcoT	1	0.10	0.754^{NS}	0.85	0.366^{NS}	0.56	0.463^{NS}	1.43	0.245^{NS}
Residual	21								
Total	31								
cv%		23.3		31.0		24.9		24.9	

NS=non-significant; * = P< 0.05

Table 5.3: Response of *Themeda triandra* above ground biomass (g pot^{-1}) to applications of EcoT and B77 to Optimum Mine soil.

	EcoT		
B77	Without	With	Means
Without	5.74a	4.30b	5.02
With	4.75a	5.45a	5.10
Means	5.25	4.88	

Values with letters in common are not significantly different P=0.05

$LSD_{P=0.05}$ marginal means= 0.87

$LSD_{P=0.05}$ body of table= 1.22

Table 5.4: Response of *Themeda triandra* above ground: below ground biomass ratio to applications of B77 and B69 to Optimum Mine soil.

	B77		
B69	Without	With	Means
Without	1.05a	0.76b	0.91
With	0.96ab	1.02a	0.99
Means	1.01	0.89	

Values with letters in common are not significantly different P=0.05

$LSD_{P=0.05}$ marginal means= 0.17

$LSD_{P=0.05}$ = body of table=0.25

Table 5.5: Analysis of variance for *Cynodon dactylon* biomass (g pot^{-1}) on Optimum Mine soil, using three soil microorganisms (trial M2), P= 0.05, significant effects in bold.

		Above biomass		Below biomass		Total biomass		Above: Below ratio	
S.O.V	d.f	v.r	F pr.	v.r	F pr.	v.r	F pr.	v.r	F pr.
Rep	3	1.49		2.79		1.20		2.11	
B69	1	1.43	0.245^{NS}	8.96	**0.007***	5.07	**0.035***	4.82	**0.040***
B77	1	3.20	0.880^{NS}	0.80	0.382^{NS}	3.47	0.076^{NS}	0.28	0.604^{NS}
EcoT	1	1.78	0.197^{NS}	3.53	0.074^{NS}	0.10	0.753^{NS}	2.28	0.146^{NS}
B69.B77	1	1.52	0.231^{NS}	2.01	0.171^{NS}	2.63	0.120^{NS}	0.09	0.767^{NS}
B69.EcoT	1	0.62	0.440^{NS}	2.33	0.141^{NS}	0.00	0.990^{NS}	1.64	0.214^{NS}
B77.EcoT	1	0.14	0.716^{NS}	0.12	0.729^{NS}	0.21	0.654^{NS}	0.29	0.598^{NS}
B69.B77.EcoT	1	0.23	0.637^{NS}	5.56	**0.028***	1.93	0.179^{NS}	1.79	0.195^{NS}
Residual	21								
Total	31								
cv%		13.90		28.2		13.3		32.9	

NS=non-significant; * = P< 0.05

Table 5.6: Response of *Cynodon dactylon*, below biomass (g pot^{-1}) to the applications of B69 to Optimum Mine soil.

B69	
Without	With
4.83a	3.58b

Different letters indicate a significantly different P=0.05

$LSD_{P=0.05}$= 0.87

Table 5.7: Response of *Cynodon dactylon*, total biomass (g pot^{-1}) to applications of B69 to Optimum Mine soil.

B69	
Without	With
22.30a	20.05b

Different letters indicate a significantly different P=0.05

LSD $_{P=0.05}$= 2.08

Table 5.8: Response of *Cynodon dactylon*, above ground: below ground biomass ratio to applications of B69 to Optimum Mine soil.

B69	
Without	With
3.93b	5.09a

Different letters indicate a significantly different P=0.05

LSD $_{P=0.05}$=1.09

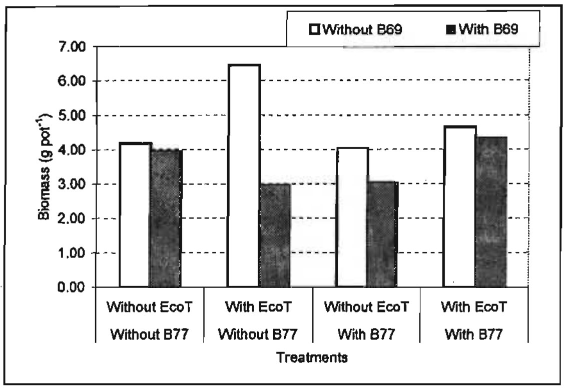

Figure 5.1: Mean biomasses for *Themeda triandra* (g pot^{-1}): below ground biomass, three-way interactions. The control (no treatment) was compared to all other treatments, none of the differences were significant P= 0.05.

Table 5.9: Analysis of variance for *Themeda triandra* biomass (g pot^{-1}) on Syferfontein Mine soil, using three soil microorganisms (trial M3), P= 0.05, significant effects in bold.

		Above biomass		Below biomass		Total biomass		Above: Below ratio	
S.O.V	d.f (m.v.)	v.r	F pr.	v.r	F pr.	v.r	F pr.	v.r	F pr.
Rep	3	1.58		3.74		3.23		2.92	
B69	1	4.41	**0.049***	5.83	**0.025***	12.73	**0.002***	0.62	0.439^{NS}
B77	1	0.00	0.947^{NS}	5.88	**0.025***	4.30	0.051^{NS}	3.42	0.079^{NS}
EcoT	1	0.85	0.368^{NS}	0.65	0.430^{NS}	1.83	0.191^{NS}	0.03	0.592^{NS}
B69.B77	1	2.86	0.106^{NS}	0.15	0.704^{NS}	0.86	0.364^{NS}	0.09	0.762^{NS}
B69.EcoT	1	0.19	0.668^{NS}	0.03	0.858^{NS}	0.22	0.642^{NS}	0.01	0.929^{NS}
B77.EcoT	1	0.79	0.385^{NS}	6.50	**0.019***	2.17	0.157^{NS}	5.93	**0.024***
B69.B77.EcoT	1	0.03	0.854^{NS}	1.42	0.247^{NS}	1.29	0.270^{NS}	1.69	0.208^{NS}
Residual	20 (1)								
Total	30 (1)								
cv%		29.00		38.80		21.30		22.30	

NS=non-significant; * = P< 0.05

Table 5.10: Response of *Themeda triandra* above ground biomass (g pot^{-1}) to applications of B69 to Syferfontein Mine soil.

B69	
Without	With
16.02a	12.91b

Different letters indicate a significantly different P=0.05
LSD$_{P=0.05}$= 0.87

Table 5.11: Response of *Themeda triandra* below ground biomass (g pot^{-1}) to applications of B69 to Syferfontein Mine soil.

a)

B69	
Without	With
14.23a	10.18b

b)

B77	
Without	With
14.24a	10.18b

Different letters indicate a significantly different P=0.05
LSD$_{P=0.05}$= 3.50

Table 5.12: Response of *Themeda triandra* below ground biomass (g pot^{-1}) to applications of EcoT and B77 to Syferfontein Mine soil.

	EcoT		
B77	Without	With	Means
Without	12.78a	15.70a	14.24
With	12.99a	7.36b	13.68
Means	12.89	11.53	

Values with letters in common are not significantly different P=0.05
LSD $_{P=0.05}$ marginal means= 3.50
LSD $_{P=0.05}$ body of table= 4.94

Table 5.13: Response of *Themeda triandra* total biomass (g pot^{-1}) to applications of B69 to Syferfontein Mine soil.

B69	
Without	With
30.30a	23.10b

Different letters indicate a significantly different P=0.05
LSD $_{P=0.05}$= 4.19

Table 5.14: Response of *Themeda triandra* above ground: below ground biomass ratio to applications of EcoT and B77 to Syferfontein Mine soil.

	EcoT		
B77	Without	With	Means
Without	0.56ab	0.48b	0.52
With	0.54b	0.67a	0.61
Means	0.55	0.48	

Values with letters in common are not significantly different P=0.05
LSD $_{P=0.05}$ marginal means= 0.09
LSD $_{P=0.05}$ body of table= 0.13

a)

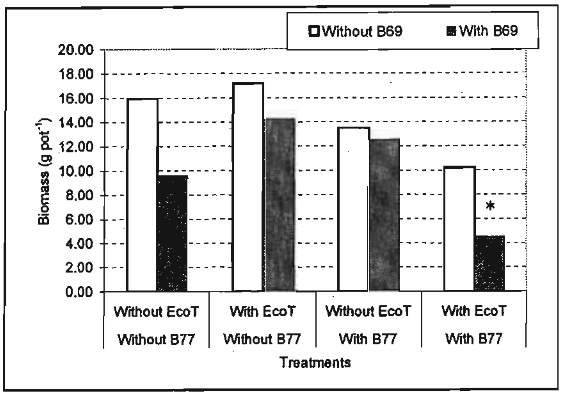

Figure 5.2: Mean biomasses for *Themeda triandra* (g pot^{-1}): below ground biomass, three-way interactions. All treatment combinations were compared to the control (no treatment), *= significantly different, P=0.05.

Table 5.15: Analysis of variance for *Cynodon dactylon* biomass (g pot^{-1}) on Syferfontein Mine soil, using three soil microorganisms (trial M4), P= 0.05.

		Above biomass		Below biomass		Total biomass		Above: Below ratio	
S.O.V	d.f	v.r	F pr.	v.r	F pr.	v.r	F pr.	v.r	F pr.
Rep	3	1.17		0.84		1.43		0.27	
B69	1	0.38	0.543^{NS}	0.28	0.604^{NS}	0.21	0.652^{NS}	1.09	0.308^{NS}
B77	1	0.12	0.734^{NS}	0.96	0.338^{NS}	0.32	0.577^{NS}	0.01	0.930^{NS}
EcoT	1	0.46	0.507^{NS}	0.03	0.858^{NS}	0.47	0.501^{NS}	0.03	0.857^{NS}
B69.B77	1	0.04	0.845^{NS}	0.30	0.591^{NS}	0.00	0.957^{NS}	0.32	0.579^{NS}
B69.EcoT	1	0.01	0.909^{NS}	1.73	0.203^{NS}	0.19	0.671^{NS}	1.15	0.296^{NS}
B77.EcoT	1	2.23	0.150^{NS}	0.31	0.586^{NS}	2.41	0.135^{NS}	0.02	0.903^{NS}
B69.B77.EcoT	1	0.60	0.448^{NS}	2.43	0.134^{NS}	1.24	0.277^{NS}	1.25	0.276^{NS}
Residual	21								
Total	31								
cv%		13.70		24.20		12.60		26.60	

NS=non-significant; * = P< 0.05

5.3.1. Results summary

- In the trial containing Optimum Mine soil and *T. triandra*, the B77 and EcoT interactions for the above ground biomass, was significant (P=0.018). It was found that EcoT significantly decreased the above ground biomass only when B77 was not applied (Table 5.4).

- In the same trial, the B69 and B77 interaction was found to be significant (P=0.041) on the A: B ratio. It appeared that the addition of B77 significantly reduced the A: B ratio compared to the control and when both B77 and B69 where applied.

- In the Optimum Mine soil and *Cynodon dactylon* trial the B69, B77 and EcoT interactions were significant in the below ground biomass (P=0.028). It was shown that EcoT, when applied by it self, significantly increased below ground biomass.

- In the main effects B69 was shown to significantly reduce below ground biomass (P=0.007) (Table 5.6).

- The total biomass in this trial was also found to be significantly reduced (P=0.035) when B69 was added (Table 5.7). The significant above ground: below ground biomass ratio found when B69 was applied, appeared to be caused by the negative effect B69 has on the below ground biomass, rather than its promotion of the above ground biomass.

- In the trial containing Syferfontein Mine soil and *T. triandra*, B77 and EcoT had a significant effect on the below ground biomass (P=0.019). The application of B77 and EcoT caused a significant decrease in the below ground biomass (Table 5.12).

- The three-way interactions, although not significant in the ANOVA, when comparing the control (no treatment) with EcoT, B77 and B69 treatments, the treatments produced a significantly lower below ground biomass than the control (Fig. 5.2).

- It was also found the B69 significantly reduced above ground biomass (P=0.049) and total biomass (P=0.002).

- In the B77 and EcoT interactions, the A: B ratio was significant (P=0.024). The application of both microbes significantly promoted above ground biomass compared to when either were applied by themselves.

5.4. DISCUSSION

In the Optimum Mine soil and *T. triandra* trial it was found that the B77 and EcoT interactions were significant (P=0.018). The addition of EcoT by itself significantly reduced above ground biomass (by approximately 21%) compared to when B77 and EcoT were applied together (Table 5.3). This increase of above ground biomass with the addition of B77 could either be due to the beneficial effect of B77 on plant growth (counteracting the negative affect of EcoT) or the suppression of EcoT by B77 (Pennanen *et al.* 1998) and thus reducing its harmful affect on above the ground biomass. The A: B ratio of B77 by itself was significantly lower in the B69 and B77 interactions.

The interactions between B69, B77 and EcoT in the Optimum Mine soil and *C. dactylon* interaction tests were found to be significant (P=0.028). But when comparing the control with each of the treatments (Bonferroni test) none were found to be significant. However using the standard LSD when EcoT was applied by itself (in this interaction), it caused a significantly higher below ground biomass. Total biomass and below ground biomass appeared to be significantly reduced when B69 was applied (main effect).

In the Syferfontein Mine soil and *T. triandra* trials, the B77 and EcoT interactions were significant for below ground biomass (P=0.019) and A: B ratio (P=0.024). In the below ground biomass, the microbes when added together, produced about 43% less biomass than the control (no treatment). When compared to EcoT – when applied by itself – the combination produced 51% less biomass while B69 when applied by itself produced very similar results to the control (Table 5.12). From this it can be seen that when the microbes B77 and EcoT are applied individually, they improved the below ground biomass. Although not significantly higher than the control, a difference could be seen. This would tend to indicate that the microbes were having a beneficial effect, possibly releasing nutrients as they decomposed the soil organic matter (Schroeder & Sprague 1994; Brady & Weil 2002). In the A: B ratio B77 and EcoT, when applied together, had the highest significant ratio when compared to B77 and EcoT by themselves. This high ratio however, would imply a suppression of below ground biomass rather than the promotion of above ground biomass, even the B69, B77 and EcoT interactions were not significant in the ANOVA (Table 5.9). When comparing the control with the B77, EcoT and B69 treatments, these were found to contain significantly less (72%) below ground biomass (Fig. 5.2). Again this would suggest that it would not be advisable to apply all microbes simultaneously. The negative effect that this combination of microbes seemed to exert could possibly be due to the competition for food (Roux 1969). B69 appeared to have a negative affect on above ground biomass, below ground biomass and total biomass of the *T. triandra*. These effects were only obvious in the main treatment effects in this trial (Tables 5.10, 5.11a and 5.13). There were no significant interactions experienced in the Syferfontein Mine soil and *C. dactylon* trial and therefore microbes did not appear to have any significant affects.

From this short-term study, the application of microbes to Optimum Mine and Syferfontein Mine soil while growing *T. triandra* and *C. dactylon* does not appear to be advisable. If microbes had to be selected from this range, EcoT and B77 applied by themselves would be preferred. However, there is no doubt microbes are important in the soil system and have an essential role to play in plant growth (Roux 1969; Jackson 1993; Schroeder & Sprague 1994).

Although *Trichoderma* spp. (Parkinson & Bhatt 1974) and *Bacillus* spp., more specifically *B. subtilis*, have been found in certain grassland soils (Harris 1971; Lowe & Paul 1974) this would not necessarily be the case in the natural grasslands near Optimum Mine and Syferfontein Mine. It would therefore be advisable to establish which are the dominant microorganism groups associated with the grassland soil and vegetation (Paul *et al.* 1979) before species are selected to promote plant growth.

6. The short-term effect of a legume on the growth of *Themeda triandra*

6.1. INTRODUCTION

Lucerne is a deep-rooted upright legume. It is grown around the world and is recognised as high value perennial forage species. It can tolerate a wide range of conditions, from cold winters to hot summers. Ideal conditions for lucerne are, however, deep, well drained calcareous to loamy soils. The recommended pH levels are between 6.5 and 7.5. If the soil is acidic, it should be limed to pH of about 6.0 to 6.5 (Donaldson 2001).

Legumes can supply up to 300 kg N ha^{-1} into a system. However, this transfer to the grass takes place via urine and dung and the decay of the legume root nodules (Donaldson 2001). Legumes have the ability to fix nitrogen due to *Rhizobium* and related bacteria that form nodules on the legume's roots (van Egeraat 1975). Legumes are quite specific about the *Rhizobium* and related bacterial species and strain; for example, lucerne requires *S. meliloti* (Allen & Allen 1981).

In a grass-legume system the balance between grass and legumes is not easy to maintain (Bartholomew 2001; Donaldson 2001) but this can be manipulated by varying nutrient availability (Donaldson 2001). The competition between plants therefore needs to be taken into consideration. The aim of this study was to determine if in the short term, there would be any effect on grass growing in conjunction with a legume.

6.2. MATERIALS AND METHODS

The Legume Trial was conducted in the Grassland Science greenhouse at the University of KwaZulu-Natal, Pietermaritzburg. The capping soil used was collected from two stockpiles at Optimum Mine and two stockpiles at Syferfontein Mine in Mpumalanga (Chapter 3.2). The soils from Optimum Mine were mixed, as were the soils from Syferfontein Mine. For each trial the soil was crushed to break down any large soil aggregates that may have been present. Plastic bags were placed in the 240 mm diameter (approximately 5500 mL) pots to avoid nutrients being leached. The pots were filled with soil to about 20 mm below the rim.

The experiment consisted of two separate trials, one on Optimum Mine soil and the other on Syferfontein Mine soil. The Optimum Mine trial was a 2^3 factorial arranged as a RCBD with four replications, and the Syferfontein Mine trial was a 2^2 factorial with five replications arranged as a RCBD.

The both trials used *Themeda triandra* plugs (seedlings) and *Medicago sativa* seedlings (cultivar Sequel). The *T. triandra* seeds used were collected from the Ermelo area in Mpumalanga and grown at TopCrop Superlawn Nursery. The lucerne seeds were inoculated with *Sinorhizobium meliloti*, and grown in the greenhouse at the University of KwaZulu-Natal. All lucerne seedlings developed root nodules, which were red in colour, and were therefore effective. The seedlings were seven weeks old when they were planted into the trials. Two plugs either of *T. triandra* alone or *T. triandra* with *M. sativa* (lucerne) were planted in each pot (Fig. 6.1). Optimum Mine soil required applications P and K while Syferfontein Mine soil only required P (Table 6.1). Both soils were analysed at Cedara (Table 6.1) (Hunter 1975; Farina 1981). The pots were watered as required.

6.2.1. Phosphorus application

Phosphorus was applied in the form of single super phosphate (10.5%) It was applied at 20 kg P ha^{-1} for the Optimum Mine soil and at 55 kg P ha^{-1} for the Syferfontein soil. Applications were applied and mixed into the soil before the plugs were planted. The application rates were calculated per pot (Appendix 22).

6.2.2. Potassium application

Potassium was applied in the form of KCl (50%). This was applied and mixed into the soil before the plugs were planted. The Optimum Mine soil had a recommended application rate of 30 kg K ha^{-1}. The rate was calculated per pot (Appendix 23).

Table 6.1: Summary of soil analysis

Soil ID	P	K	Ca	Mg	Exch. Acidity	Total cations	Acid sat.	pH (KCl)	Zn	Mn	NIRS Organic carbon	NIRS clay
	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	cmol L^{-1}	cmol L^{-1}	%		mg L^{-1}	mg L^{-1}	%	%
Optimum 1	18	138	616	226	0.05	5.34	1	5.04	3.8	11	0.9	49
Optimum 2	22	161	863	332	0.08	7.53	1	5.1	4.3	9	0.8	44
Syferfontein 1	2	175	1657	1018	0.06	17.15	0	6.7	0	1	0.9	39
Syferfontein 2	1	181	1811	1013	0.04	17.9	0	6.63	0.5	2	1.3	38

The above ground *T. triandra* biomass for both trials was harvested after eight weeks of growth and was dried at 60°C in a drying oven. In the case where there were two *T. triandra* plants in a pot, both were harvested, and their mean weight per plug was derived. All the dry weights were recorded and analysed using an ANOVA and significant differences were determined at the 5% significance level. In the third order interaction, the control (no treatments) was compared to the treatment mean. This was done using Bonferroni adjusted LSDs for multiple comparisons (Zar 1996). The above ground biomasses were then pooled according to treatment, and the treatments were then analysed for protein at the Cedara Feed Laboratory, using a LECO CNS 2000. The protein values were then converted to N% by dividing by 6.25 (Matejovic 1996). Non-significant means tables for Optimum Mine soil were recorded in Appendix 24.

Figure 6.1: Treatments showing two plugs of *T. triandra* per pot (left) and one each of *T. triandra* and lucerne (right) planted in Syferfontein Mine soil, at the beginning of the trial.

6.3. RESULTS

Table 6.2: Analysis of variance for *Themeda triandra* above ground biomass (g pot^{-1}) produced on Optimum Mine soil, when grown with or without P and K fertilizer and lucerne.

S.O.V	d.f	v.r	F pr.
Rep	3	3.82	
Legume	1	20.71	**<0.001***
P	1	21.21	**<0.001***
K	1	1.17	0.291^{NS}
Legume.P	1	3.39	0.080^{NS}
Legume.K	1	0.66	0.426^{NS}
P.K	1	2.30	0.144^{NS}
Legume.P.K	1	0.00	0.957^{NS}
Residual	21		
Total	31		
cv%		29.2	

NS=non-significant; * = P< 0.05 significant effects in bold

Table 6.3: Table of means for *Themeda triandra* above ground biomass (g pot^{-1}) main effects.

a)

Legume	
Without	With
2.17a	1.66b

b)

Phosphorus	
Without	With
1.65b	2.71a

Different letters indicate a significantly different P=0.05
$LSD_{P=0.05}$= 0.48

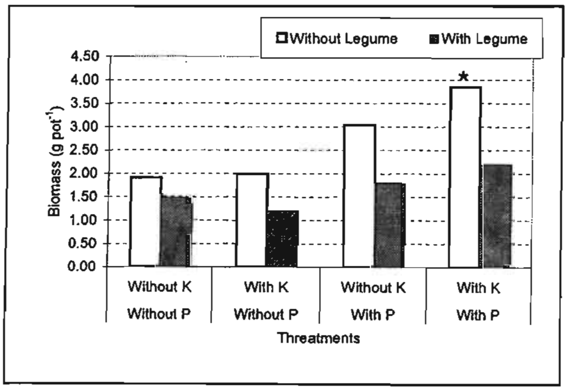

Figure 6.2: Means for *Themeda triandra* above ground biomass (g pot^{-1}) three-way interactions. All treatment combinations were compared to the control (no treatment), *= significantly different, P=0.05.

Table 6.4: Analysis of variance for *Themeda triandra* above ground biomass (g pot^{-1}) produced on Syferfontein Mine soil, when grown with or without P fertilizer or lucerne.

S.O.V	d.f	v.r	F pr.
Rep	4	2.02	
Legume	1	31.68	**<0.001***
P	1	30.49	**<0.001***
Legume.P	1	8.69	**0.012***
Residual	12		
Total	19		
cv%		26.7	

NS=non-significant; * = $P< 0.05$ significant effects in bold

Table 6.5: Response of *Themeda triandra*, above ground biomass (g pot^{-1}) to lucerne and applications of P to Syferfontein Mine soil.

	Phosphorus		
Legume	Without	With	Means
Without	1.30b	2.88a	2.09
With	0.80b	1.28b	1.04
Means	1.05	2.08	

Values with letters in common are not significantly different P=0.05

$LSD_{P=0.05}$ marginal means

$LSD_{P=0.05}$ body of table= 0.57

Table 6.6: Nitrogen percentage (%) for *Themeda triandra* above ground biomass grown on Optimum Mine and Syferfontein Mine capping soil, with various soil ameliorants.

Treatment	Optimum soil N%	Nitrogen N%
K	1.35	-
P	1.09	1.43
Control	1.35	1.33
Legume	0.91	1.25
Legume.P	1.04	1.06
Legume.K	0.97	-
P.K	0.92	-
Legume.P.K	0.85	-
Means	1.06	1.27

6.3.1. Results summary

- In the Optimum Mine trial, the *T. triandra* herbage was found to be significantly lower ($P<0.001$) when grown with lucerne, than without the presence of lucerne.
- The application of P was found to significantly increase above ground biomass ($P>0.001$).
- When comparing the control (no treatment) above ground biomass with the biomass of various treated Optimum Mine soil pots, only those containing P and K were found to be significant, using the Bonferroni test (Fig. 6.2).
- In the Syferfontein Mine trial the legume and P interaction was found to be significant ($P=0.012$). Phosphorous was found to increase the above ground biomass from the control only when lucerne was not present.
- For *T. triandra,* the above ground biomass of the treatment's K, P and control on Optimum Mine soil had a higher N% than the mean (1.06 N %). On Syferfontein Mine soil the treatments P and control had a higher N% than the mean (1.27 N%) (Table 6.6).

6.4. DISCUSSION

In the Optimum Mine's short-term legume trial it was seen that the legume had a significantly negative effect ($P<0.001$) on the above ground biomass of *T. triandra*. In Table 6.6 there was no increase in nitrogen percentage when *T. triandra* is grown in the presence of lucerne when compared to the overall mean. This was not surprising considering legumes transfer most of their nitrogen to the grass via the decomposition of their root nodules and through the deposition of urine and dung (Donaldson 2001). Phosphorous also had a significant effect on the above ground biomass yields ($P<0.001$). This was expected as the soil was originally deficient in phosphorous, therefore the correction of the nutrient deficiency improved plant growth (Miles & Manson 2000). Although the ANOVA (Table 6.2) does not express the legume, P and K interactions as significant, when using the Bonferroni test, the treatments, K and P, in the three-way interactions are shown to be significantly higher than the control by 50%. This would indicate that the application of K and P would improve above ground plant growth. Once again this was expected because Optimum Mine soil was deficient in both these nutrients (Table 6.1).

For the Syferfontein Mine trial the interactions between legume and P were found to be significant ($P=0.012$), along with their respective main effects. The application of P by itself in these interactions once again significantly increased above ground biomass of *T. triandra*. However, when applied in conjunction with the legume treatments, the above ground biomass showed no significant difference from the control treatments and the legume (no P) treatments, i.e., the legume used up the P which otherwise enhanced growth.

The addition of macronutrients P and K will improve the growth of plants if they are deficient in the soil (Miles & Manson 2000; Brady & Weil 2002). However, the growth of a legume in the short-term does not appear to be beneficial. This is probably due to plant competition (Donaldson 2001). There also appears to be no obvious improvement in percentage N in the above ground biomass of *T. triandra*, this is however not a conclusive indicator that either more or less N is available to a plant, but further investigations should be undertaken on a longer timescale before any findings can be reached.

7. The effect of lime and fly ash on the growth of *Themeda triandra* and *Medicago sativa* (lucerne)

7.1. INTRODUCTION

Fly ash, a by-product of coal combustion consisting of tiny glass-like particles (Carlson & Adriano 1993; Gupta *et al.* 2002) is produced at an estimated rate of 25Mt annually in South Africa. The chemical, physical and mineral properties of fly ash can vary from source to source as its composition depends on the parent coal, the method of combustion, the types of emission control equipment used, and how the fly ash is handled and stored (Adriano & Weber 2001).

Some of the most common methods of fly ash disposal are in landfills (Schumann & Sumner 1999) and ash dams (van den Berg *et al.* 2001) but according to Schumann & Sumner (1999) these traditional sites in future will no longer comply with the ever-increasing restraints placed upon them by environmental bodies. A possible solution is to use the fly ash in agricultural and land rehabilitation projects. This is because fly ash has the potential to be used as a fertilizer (Schumann & Sumner 1999; Gupta *et al.* 2002) and a liming agent (Schumann & Sumner 1999). Various studies have been done in which fly ash has been added to acidic mine soils, and the resulting crop yields have increased (Adriano *et al.*1980). Kovacic & Hardy (1972) and Fail & Wochok (1977) suggest that the increase in yields occurring in crops with fly ash, as a soil ameliorant is due to the increase in nutrients available and fly ash's neutralising ability. The neutralising ability of fly ash raised the pH of soil ameliorated with weathered fly ash from <6.0 to ≈8.0 and soil ameliorated with unweathered ash from <6.0 to ≈12 (Adriano *et al.* 1980).

The primary aim of this study was to determine whether fly ash could be used as a liming agent when growing *T. triandra* and lucerne in acidic mine capping soil. The secondary aim was to determine the effects in plant growth between, untreated soils and those with fly ash and/or dolomitic lime added.

7.2. MATERIALS AND METHODS

The experimental design of the pot trial was a 2^3 factorial arranged as a RCBD, with four replications. It was run in a greenhouse at the University of KwaZulu-Natal, Pietermaritzburg, KwaZulu-Natal. The thirty-two, 200 mm diameter pots were placed in the middle of the greenhouse, running from the extractor fan to the wet wall in direction, i.e., longitudinally. In the fourth week the pots were moved to another greenhouse at the University of KwaZulu-Natal, because the roof came off during a windstorm. Care was taken to move the trial as quickly as possible and with as little disturbance to the plants as possible, while maintaining the original randomisation.

The three treatments were dolomitic lime and fly ash. The species used in the trial were *Themeda triandra* and *Medicago sativa* (cultivar Sequel). The *T. triandra* plugs were germinated from seed collected in the Ermelo area, Mpumalanga. The lucerne was inoculated with *Sinorhizobium meliloti*, and during planting only seedlings with red effective root nodules were used.

Soil for the trial was obtained from Optimum Mine open cast colliery in Mpumalanga. The soil was collected from three different capping soil stockpiles on the mine. These were along with the fly ash analysed by Cedara (Hunter 1975; Farina 1981) (Table 7.1)(Table 7.2). Due to there not being a sufficient amount of one soil to complete the trial, the two most similar soils (Table 7.1) were mixed together. The mixed soil required K and P. The suggested fertilizer application rates for N, P and K were for 12 t ha^{-1} of *Eragrostis curvula* (dryland). If two different application rates were recommended for the different soils then the higher of the two recommended amounts was used. These amounts were used to calculate how much fertilizer was required per pot. The fertilizer, dolomitic lime and fly ash were applied and mixed into the pot soil before planting.

Table 7.1: Analysis of soil obtained from Optimum Mine used as capping soil.

Soil ID	P	K	Ca	Mg	Exch. Acidity	Total cations	Acid sat.	pH (KCl)	Zn	Mn	NIRS Organic carbon	NIRS clay
	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	cmol L^{-1}	cmol L^{-1}	%		mg L^{-1}	mg L^{-1}	%	%
Optimum 1	1	61	61	31	0.66	1.38	48	4.17	0.2	2	<0.5	49
Optimum 2	2	95	104	35	0.77	1.82	42	4.07	1.5	3	-	26

Table 7.2: Analysis of fly ash obtained from a Vereeniging power station (Cedara Soil Salinity Laboratory).

Neutralising Value A.O.A.C method	Composition Soluble in acid			Sieve analysis (as is basis)				
%	%			%				
	Ca	K	Mg	>1.7mm	1.7-1.00mm	1.00-0.5mm	0.5-0.25mm	<0.25mm
2.000	0.86	0.002	0.001	0.009	0.49	5.63	15.48	77.51

The fly ash was acquired from a power station in Vereeniging, Gauteng. In order for the equivalent amount of dolomitic lime and fly ash to be applied, the neutralising value (Horwitz 1980) for each was obtained from Cedara. Lime was applied at 1 t ha^{-1}(dolomitic lime 88.3% neutralising value), therefore the respective quantities of lime and fly ash were calculated per pot (Appendix 25).

The pots were watered every day as required. Since tap water was used, the pH$_{(water)}$ (Thomas 1996) and electron conductivity (EC) using a CDM83 conductivity meter, was recorded once a week, in case any major fluctuations were experienced. The pH$_{(water)}$ (Thomas 1996) of the soil in each pot was tested at the beginning and at the end of the trial. Two pots containing the fertilizer applications and either fly ash or lime, also stood in the greenhouse for the duration of the trial. The pH of the soil in both of the pots was also recorded in the beginning and at the end of the trial. All the initial pH reading was done when treatments had been mixed into the soil. The trial was run for 7 weeks.

The above and belowground biomass was harvested separately and dried at 60°C for 24 hours. One *T. triandra* plant (Rep 4 control) died in the third week. The above and below ground biomass were weighed, and the total and above: below ground ratios (A: B ratios) were calculated, these data was analysed using ANOVA at the 5% level of significance.

The initial and final pot pH for each pot was also analysed using ANOVA, along with a paired t-test at the 5% level of significance. Non-significant means tables have placed in the appendices, above ground biomass tables (Appendix 26), below ground biomass (Appendix 27), total biomass (Appendix 28), A: B ratios (Appendix 29), initial pH (Appendix 30) and final pH (Appendix 31).

7.3. RESULTS

Table 7.3: Analysis of variance for *Themeda triandra* and lucerne biomass (g pot^{-1}) on Optimum Mine soil, comparing fly ash and lime, P= 0.05.

		Above biomass		Below biomass		Total biomass		Above: Below ratio	
S.O.V	d.f	v.r	F pr.	v.r	F pr.	v.r	F pr.	v.r	F pr.
Rep	3	0.71		0.92		0.64		1.20	
Fly ash	1	0.05	0.827^{NS}	1.50	0.234^{NS}	0.42	0.526^{NS}	0.01	0.910^{NS}
Lime	1	0.24	0.629^{NS}	0.11	0.741^{NS}	0.22	0.642^{NS}	0.13	0.720^{NS}
Species	1	2.12	0.160^{NS}	2.29	0.146^{NS}	2.60	0.123^{NS}	1.75	0.201^{NS}
Fly ash.Lime	1	0.43	0.521^{NS}	0.08	0.780^{NS}	0.32	0.579^{NS}	0.91	0.351^{NS}
Fly ash.Species	1	0.13	0.723^{NS}	1.74	0.202^{NS}	0.61	0.446^{NS}	0.87	0.362^{NS}
Lime.Species	1	1.05	0.318^{NS}	0.06	0.801^{NS}	0.65	0.429^{NS}	1.67	0.211^{NS}
Fly ash.Lime.Species	1	0.84	0.371^{NS}	1.09	0.308^{NS}	1.10	0.306^{NS}	0.29	0.594^{NS}
Residual	20 (1)								
Total	30 (1)								
cv%		80.10		69.50		69.60		35.30	

NS=non-significant

Table 7.4: Analysis of variance for initial and final soil pH values with all treatments added, at the significance level of $P= 0.05$.

		Initial pH		Final pH	
S.O.V	d.f	v.r	F pr.	v.r	F pr.
Rep	3	0.04		1.58	
Fly ash	1	57.59	**<.001***	0.11	0.744^{NS}
Lime	1	15.05	**<.001***	1.65	0.213^{NS}
Species	1	1.70	0.206^{NS}	2.59	0.122^{NS}
Fly ash. Lime	1	7.92	0.010^{NS}	0.35	0.561^{NS}
Fly ash. Species	1	0.18	0.674^{NS}	0.00	0.979^{NS}
Lime. Species	1	0.08	0.781^{NS}	0.40	0.533^{NS}
Fly ash. Lime. Species	1	0.04	0.853^{NS}	0.36	0.554^{NS}
Residual	21				
Total	31				
cv%		6.90		7.20	

NS=non-significant; * = $P< 0.05$, significant effects in bold

Table 7.5: Table of significant means for initial soil pH main effects.

a)

Fly ash	
Without	With
5.47b	6.31a

b)

Lime	
Without	With
5.74b	6.31a

Different letters indicate a significantly different $P=0.05$

$LSD_{P=0.05}$= 0.31

7.3.1 Results summary

- No significant differences were found in the above ground biomass, below ground biomass, total biomass and A: B ratios at the 5% significance levels.
- In the three way interactions the fly ash treatment had generally high yields in the above, below and total biomass results - although these were not significant.
- As was expected, lime and fly ash significantly increased the soil pH (< 0.001) in the initial pH results. However, in the final soil pH readings, none of the values were significantly different.

- The paired t-test compared the initial and final soil pHs, and showed that they were significantly different ($P<0.001$). The initial pHs were higher than the final pHs in all treatments (Appendix 32). The soil in two pots not containing plants also decreased in pH (Appendix 32).
- An interesting observation was the lack of root nodules on the lucerne's roots. However, these were present when they were planted.

7.4. DISCUSSION

In the fly ash and lime trial using Optimum Mine's soil there appeared to be no significant interactions on the growth *T. triandra* and lucerne (Table 7.3). This was possibly due to the levels of fly ash and lime not being sufficient to cause an effect. In Carlson & Adriano (1993), a table of potential effects of fly ash on terrestrial ecosystems used three possible fly ash application guidelines. These were less than 100 t ha^{-1}, 100 t ha^{-1} to 400 t ha^{-1} and more than 400 t ha^{-1}. Although fly ash is very variable (van den Berg *et al.* 2001), due to its low liming ability (Appendix 25) about 18 times more fly ash would be required than lime, which could possibly cause a problem with transportation.

When testing the pH values of the soil the initial pH values when lime and fly ash was applied were significant ($P<0.001$). However, in the final soil, pH results were not found to be significant. This probably would imply once again that not sufficient of either were applied. When comparing the initial and final soil pH's for all treatments, it was found that all pH's significantly decreased. This was probably due to the increase in NH_4^+ and therefore the H^+ ions released by the nitrogen fertilizer, which decreased the soil pH. If sufficient lime was added the exchangeable acidity (Al^+ and H^+) should decrease and soil pH should increase (Miles & Manson 2000). What was interesting was the loss of root nodules experienced by the lucerne plants. This occurred due to the intolerance of *Sinorhizobium meliloti* to pH's lower than 5.8-5.9 (Date 1970), as was the case in this trial (Appendix 33). This aspect will have to be corrected by the mines if legumes are to be used in mine rehabilitation.

8. An overview of the research

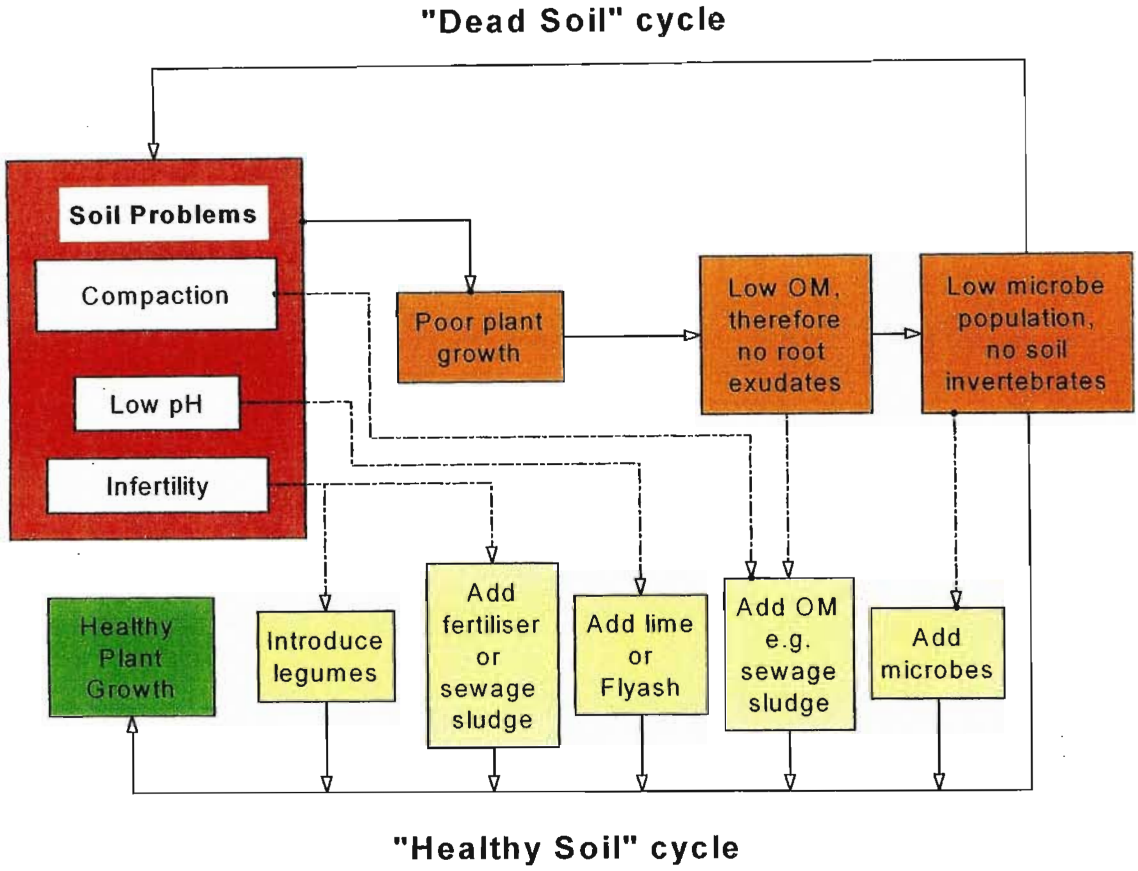

Figure 8.1: A conceptual model of soil rehabilitation problems and possible solutions. When no action is taken to alleviate the soil problems, a "dead soil" cycle is likely to occur, whereas the addition of appropriate soil ameliorants can convert the soil into a "healthy soil" cycle. The growth of plants and the addition of organic matter also promote a "healthy soil" cycle by alleviating soil compaction.

8.1. CONCLUSIONS

- The pastures that had been rehabilitated for about five years at the Kromdraai, Syferfontein and Optimum mines in the Witbank area had approximately half the number of species found in the undisturbed veld of those mines.
- In the rehabilitated sites it was often found that only one or two species of improved pasture grasses (that had been seeded) dominated.
- From the Umlazi Landfill Trial it was found that both fertilizer and sewage sludge significantly increased the above ground biomass, below ground biomass and total biomass of *T. triandra*.
- It was shown that there was no significant difference in plant biomass between the sludge and fertilizer treatments. This was probably due to the equivalent amounts of P added (Fig. 4.2b).
- Lime had a negative effect on the above ground biomass and the below ground biomass, although the microbes did alleviate this negative effect.
- K-humate had no effect on the growth of *T. triandra*.
- In the Microbe Trial, the application of EcoT, B69 and B77 generally had a negative effect or no effect on plant biomass.
- In two instances, the application of B77 alleviated the negative effect of EcoT in the above ground biomass and the below ground biomass of *T. triandra*.
- In the Legume Trial it was shown that in the short term, growing lucerne together with *T. triandra* significantly reduced the above ground biomass of *T. triandra* on both Optimum Mine and Syferfontein Mine soil.
- The application of P significantly increased the above ground biomass of *T. triandra*, though, only in the absence of a legume.
- In the Fly Ash Trial, there were no significant treatment effects in the biomass of *T. triandra* and lucerne.
- The initial pH of the soil treated with fly ash and lime was significantly higher than those that were not treated. However, the pH of the soils were similar at the end of the trial, demonstrating the short-term effect of lime and fly ash in increasing soil pH.

- An absence of legume root nodules was observed at the end of the trial, due to soil acidity.

In summary it can be concluded that the use of various soil ameliorants, in particular fertilizer and sewage sludge, do promote plant growth and therefore this would in turn help to achieve the overall aim of promoting a healthy soil system of rehabilitated land.

Since the study had to be finished in two years, the different trials were run for a relatively short time. The time limit determined how many soil ameliorants were tested and, to a certain extent, which ameliorants were used. In the first trial soil availability was limited, therefore landfill soil had to be used instead of soil from Optimum and Syferfontein Mine. The trials were all short-term pot trials and therefore extrapolations can't be made to field conditions, although these trials do promote the understanding of the various soil ameliorants effect on *Themeda triandra, Cynodon dactylon* (Seagreen) and *Medicago sativa* (cultivar Sequel).

8.2. RECOMMENDATIONS

- In the short-term, fertilizer and sewage sludge can be used to significantly improve above ground, below ground and total biomass of *T. triandra.*
- Fertilizer and sludge were equally effective as soil ameliorants in the short term. Therefore, either can be used to improve plant growth.
- Lime reduced the yield of *T. triandra.* Therefore, it is recommended that lime not be used especially in soil with an acid saturation of approximately 1%.
- In the case of lucerne, if it is going to be used, the soil from Optimum Mine and Syferfontein Mine requires liming in order for the root nodule *Sinorhizobium* to persist. However in the short-term lucerne does not promote the growth of *T. triandra* therefore it is recommended that it should not be used.
- The application of *Trichoderma harzianum* (EcoT), *Bacillus subtilis* Strain 77 (B77) and *Bacillus subtilis* Strain 69 (B69) is not recommended, although if lime were to be applied the application of EcoT and B69 may be appropriate.

8.3. POSSIBLE RESEARCH OPPORTUNITIES

Future research should include:

- long-term trials using fertilizer, sewage sludge, microbes, lime and fly ash on mine capping soil in pots or in field trials;
- the study of a greater range of soil microbes in the natural veld and in mine soil stockpiles, and their possible use in mine rehabilitation; and
- comparing levels of lime and fly ash to alleviate soil acidity while growing *T. triandra* and legumes.

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Table of Appendices

Appendix 1

Nitrogen application rate calculations

Recommended rates:

1. 50 kg N ha^{-1}
2. 60 kg N ha^{-1}

LAN (28% N)

1. In 100 kg LAN = 28 kg N

Therefore (50kg/ 28) x 100

= 178.5714 kg LAN ha^{-1}

= (178.5714 kg LAN ha^{-1}/ 10 000 m^2) x 1000 g/1 kg

= 17.85714 g m^{-2}

Surface area of pot

Πr^2

= 3.14 x $(0.1\ m)^2$

= 0.0314 m^2

Therefore the amount of LAN per pot = 17.85714 g m^{-2} x 0.0314 m^2

= 0.561 g LAN pot^{-1}

2. 60 kg N ha^{-1} required for the second and third applications = 0.673 g LAN pot^{-1}

Appendix 2

Phosphorus application rate calculation

Recommended rate:

65 kg P ha^{-1}

Double super phosphate (10.5% P)

In 100 kg supers = 10.5 kg P

Therefore (65kg/ 10.5) x 100

= 619.0476 kg supers ha^{-1}

= (619.0476 kg supers. ha^{-1}/ 10 000 m^2) x 1000 g/ 1 kg

= 61.90476 g m^{-2}

Surface area of pot

$\prod r^2$

= 3.14 x $(0.1\ m)^2$

= 0.0314 m^2

Therefore the amount of supers per pot = 61.90476 g m^2 x 0.0314 m^2

= 1.944 g supers pot^{-1}

Appendix 3

Potassium application rate calculations

Recommended rate:

1. 80 kg K ha^{-1}
2. 120 kg K ha^{-1}

KCl (50% K)

1. In 100 kg KCl = 50 kg K

Therefore (80kg/ 50) x 100

= 160 kg KCl ha^{-1}

= (160 kg KCl ha^{-1}/ 10 000 m^{2}) x 1000 g/1 kg

= 16 g m^{-2}

Surface area of pot

Πr^2

= 3.14 x (0.1 m)^{2}

= 0.0314 m^{2}

Therefore the amount of KCl per pot = 16 g m^{-2} x 0.0314 m^{2}

= 0.502 g KCl pot^{-1}

2. 120 kg N ha^{-1} required for the second and third applications = 0.754 g KCl pot^{-1}

Appendix 4

Sewage sludge application rate calculation

Recommended rate:

P= 65 kg ha^{-1}

Per pot =1.944 g pot^{-1}

Mean P in sludge =106650 mg kg^{-1}

Therefore 106650 mg kg^{-1} / 1000

= 106.65 g P kg^{-1}

thus 106.65/106 = 1000/106.65

1 (P) g =9.376 g sludge

Therefore 1.944g x 9.376 g sludge

= 18.227 g sludge pot^{-1}

=5.805 t ha^{-1}

Appendix 5

Lime application rate calculation

Recommended rate of lime = 3 t ha^{-1}= 3000 kg ha^{-1}= 300 g m^{-2}

Surface area of pot

$\prod r^2$

$= 3.14 \times (0.1\ m)^2$

$= 0.0314\ m^2$

Therefore the amount of lime per pot = 300 g m^{-2} x 0.0314 m^2

= 9.42 g lime pot^{-1}

Appendix 6

Non-significant means main effects for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* above ground biomass (log g pot^{-1}) main effects.

a)

Humate	
Without	With
0.964	0.964

b)

Lime	
Without	With
0.980	0.947

c)

Microbes	
Without	With
0.953	0.975

d)

Soil	
Sub	Top
0.952	0.976

$LSD_{P=0.05}$= 0.06

Appendix 7

Non-significant means two-way interactions for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* above ground biomass (log g pot^{-1}) two-way interactions.

a)

	Humate	
Fertilizer	Without	With
Without	0.787	0.798
With	1.141	1.130

LSD $_{P=0.05}$= 0.09

b)

	Lime	
Fertilizer	Without	With
Without	0.813	0.772
With	1.148	1.123

c)

	Lime	
Humate	Without	With
Without	0.996	0.932
With	0.965	0.963

d)

	Microbes	
Fertilizer	Without	With
Without	0.768	0.817
With	1.138	1.133

e)

	Microbes	
Humate	Without	With
Without	0.947	0.980
With	0.958	0.970

f)

	Sludge	
Fertilizer	Without	With
Without	0.439c	1.146ab
With	1.087b	1.184a

g)

	Sludge	
Humate	Without	With
Without	0.755	1.173
With	0.770	1.158

h)

	Sludge	
Lime	Without	With
Without	0.789	1.172
With	0.737	1.158

i)

	Sludge	
Microbes	Without	With
Without	0.730	1.175
With	0.795	1.155

j)

	Soil	
Humate	Sub	Top
Without	0.946	0.982
With	0.959	0.969

k)

	Soil	
Lime	Sub	Top
Without	0.986	0.974
With	0.918	0.977

l)

	Soil	
Microbes	Sub	Top
Without	0.935	0.970
With	0.969	0.981

m)

	Soil	
Sludge	Sub	Top
Without	0.754	0.771
With	1.150	1.180

Appendix 8

Non-significant means main effects for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* below ground biomass (log g pot^{-1}) main effects

a)

Humate	
Without	With
0.797	0.785

LSD $_{P=0.05}$= 0.08

b)

Microbes	
Without	With
0.757	0.824

Appendix 9

Non-significant means two-way interactions for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* below ground biomass (log g pot^{-1}) two-way interactions

a)

	Humate	
Fertilizer	Without	With
Without	0.716	0.678
With	0.877	0.891

LSD $_{P=0.05}$= 0.11

b)

	Lime	
Fertilizer	Without	With
Without	0.753	0.641
With	0.945	0.823

c)

	Lime	
Humate	Without	With
Without	0.860	0.733
With	0.839	0.731

d)

	Microbes	
Fertilizer	Without	With
Without	0.670	0.725
With	0.844	0.924

e)

	Microbes	
Humate	Without	With
Without	0.778	0.815
With	0.736	0.834

f)

	Microbes	
Lime	Without	With
Without	0.829	0.87
With	0.685	0.779

g)

	Sludge	
Humate	Without	With
Without	0.643	0.95
With	0.669	0.9

h)

	Sludge	
Lime	Without	With
Without	0.705	0.993
With	0.607	0.857

i)

	Soil	
Humate	Without	With
Without	0.832	0.761
With	0.827	0.742

j)

	Sludge	
Microbes	Without	With
Without	0.622	0.891
With	0.691	0.958

k)

	Soil	
Microbes	Sub	Top
Without	0.822	0.692
With	0.838	0.811

l)

	Soil	
Sludge	Sub	Top
Without	0.715	0.597
With	0.944	0.906

Appendix 10

Non-significant means main effects for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* total ground biomass (log g pot^{-1}) main effects

a)

Microbes	
Without	With
1.192	1.232

b)

Humate	
Without	With
1.211	1.213

c)

Soil	
Sub	Top
1.218	1.206

Appendix 11

Non-significant mean two-way interactions for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* total ground biomass (g pot^{-1}) two-way interactions

a)

	Humate	
Fertilizer	Without	With
Without	1.073	1.075
With	1.349	1.351

LSD $_{P=0.05}$= 0.07

b)

	Lime	
Fertilizer	Without	With
Without	1.103	1.045
With	1.378	1.322

c)

	Lime	
Humate	Without	With
Without	1.251	1.171
With	1.230	1.196

d)

	Microbes	
Fertilizer	Without	With
Without	1.052	1.095
With	1.331	1.369

e)

	Microbes	
Humate	Without	With
Without	1.195	1.227
With	1.188	1.237

f)

	Microbes	
Lime	Without	With
Without	1.243	1.238
With	1.141	1.226

g)

	Sludge	
Humate	Without	With
Without	1.028	1.394
With	1.052	1.374

h)

	Sludge	
Lime	Without	With
Without	1.075	1.406
With	1.005	1.362

i)

	Sludge	
Microbes	Without	With
Without	1.009	1.375
With	1.072	1.393

j)

	Soil	
Fertilizer	Sub	Top
Without	1.027	1.121
With	1.409	1.291

k)

	Soil	
Humate	Sub	Top
Without	1.207	1.215
With	1.229	1.197

l)

	Soil	
Lime	Sub	Top
Without	1.236	1.245
With	1.200	1.167

m)

	Soil	
Microbes	Sub	Top
Without	1.206	1.178
With	1.230	1.235

Appendix 12

Non-significant means main effects for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* above ground: below ground biomass ratio main effects

a)

Microbes	
Without	With
0.196	0.151

LSD $_{P=0.05}$= 0.08

b)

Humate	
Without	With
0.167	0.179

Appendix 13

Non-significant means two-way interactions for Umlazi Landfill Trial

Table of non-significant means for *Themeda triandra* above ground: below ground biomass ratio main effects.

a)

	Humate	
Fertilizer	Without	With
Without	0.071	0.120
With	0.264	0.239

LSD= $_{P=0.05}$ 0.12

b)

	Lime	
Fertilizer	Without	With
Without	0.060	0.131
With	0.202	0.300

c)

	Lime	
Humate	Without	With
Without	0.136	0.199
With	0.126	0.233

d)

	Microbes	
Fertilizer	Without	With
Without	0.098	0.093
With	0.294	0.209

e)

	Microbes	
Humate	Without	With
Without	0.169	0.166
With	0.223	0.136

f)

	Microbes	
Lime	Without	With
Without	0.179	0.083
With	0.213	0.218

g)

	Sludge	
Humate	Without	With
Without	0.112	0.223
With	0.101	0.258

h)

	Sludge	
Lime	Without	With
Without	0.083	0.179
With	0.13	0.302

i)

	Sludge	
Microbes	Without	With
Without	0.108	0.284
With	0.104	0.197

j)

	Soil	
Fertilizer	Sub	Top
Without	0.03	0.161
With	0.216	0.267

k)

	Soil	
Humate	Sub	Top
Without	0.114	0.220
With	0.131	0.227

l)

	Soil	
Microbes	Sub	Top
Without	0.114	0.278
With	0.132	0.170

m)

	Soil	
Sludge	Sub	Top
Without	0.039	0.174
With	0.207	0.274

Appendix 14

Non-significant means for trial M1 main effects

Table of non-significant means for *Themeda triandra* above ground biomass (g pot^{-1}) main effects (M1).

a)	
B69	
Without	With
5.10	5.02

LSD= $_{P=0.05}$0.87

b)	
B77	
Without	With
5.02	5.10

c)	
EcoT	
Without	With
5.25	4.87

Table of means non-significant for *Themeda triandra* below ground biomass (g pot^{-1}) main effects.

a)	
B69	
Without	With
5.94	5.34

LSD= 1.29

b)	
B77	
Without	With
5.39	5.90

c)	
EcoT	
Without	With
5.38	5.91

Table of means non-significant for *Themeda triandra* total biomass (g pot^{-1}) main effects.

a)	
B69	
Without	With
11.04	10.36

LSD= 1.96

b)	
B77	
Without	With
10.40	11.00

c)	
EcoT	
Without	With
10.63	10.78

Table of means non-significant for *Themeda triandra* above ground: below ground biomass ratio main effects.

a)	
B69	
Without	With
0.905	0.989

LSD= 0.17

b)	
B77	
Without	With
1.005	0.889

c)	
EcoT	
Without	With
1.013	0.88

Appendix 15

Non-significant means for trial M1, two-way interactions

Table of non-significant means for *Themeda triandra* above ground biomass (g pot^{-1}), two-way interactions.

a)

	B77	
B69	Without	With
Without	5.33	4.87
With	4.71	5.87

LSD$_{P=0.05}$= 1.22

b)

	EcoT	
B69	Without	With
Without	5.48	4.72
With	5.01	5.03

Table of non-significant means for *Themeda triandra* below ground biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	5.36	6.53
With	5.41	5.27

LSD$_{P=0.05}$= 1.82

b)

	EcoT	
B69	Without	With
Without	5.49	6.4
With	5.27	5.42

c)

	EcoT	
B77	Without	With
Without	5.31	5.46
With	5.45	6.35

Table of non-significant means for *Themeda triandra* total biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	10.69	11.4
With	10.12	10.61

LSD=$_{P=0.05}$ 2.77

b)

	EcoT	
B69	Without	With
Without	10.98	11.11
With	10.28	10.45

c)

	EcoT	
B77	Without	With
Without	11.05	9.76
With	10.20	11.8

Table of non-significant means for *Themeda triandra* above ground: below ground biomass ratio two-way interactions.

a)

	EcoT	
B69	Without	With
Without	1.051	0.759
With	0.975	1.002

LSD$_{P=0.05}$=0.25

b)

	EcoT	
B77	Without	With
Without	1.124	0.885
With	0.902	0.876

Appendix 16

Non-significant means for trial M2, main effects

Table of non-significant means for *Cynodon dactylon* above biomass (g pot^{-1}) main effects.

a)

B69	
Without	With
17.47	5.02

LSD$_{P=0.05}$= 1.73

b)

B77	
Without	With
17.72	16.23

c)

EcoT	
Without	With
17.53	16.42

Table of non-significant means for *Cynodon dactylon* below biomass (g pot^{-1}) main effects.

a)

B77	
Without	With
4.39	4.02

LSD$_{P=0.05}$= 0.87

b)

EcoT	
Without	With
3.81	4.60

Table of non-significant means for *Cynodon dactylon* total biomass (g pot^{-1}) main effects.

a)

B77	
Without	With
22.11	20.25

LSD$_{P=0.05}$= 2.08

b)

EcoT	
Without	With
21.34	21.02

Table of non-significant means for *Cynodon dactylon* above ground: below ground biomass ratio main effects.

a)

B77	
Without	With
4.65	4.37

LSD$_{P=0.05}$= 1.092

b)

EcoT	
Without	With
4.19	4.11

Appendix 17

Non-significant means for trial M2, two-way interactions

Table of non-significant means for *Cynodon dactylon* above ground biomass (g pot^{-1}) two-way interactions (M2).

a)

	B77	
B69	Without	With
Without	18.72	16.21
With	16.71	16.25

LSD $_{P=0.05}$= 2.45

b)

	EcoT	
B69	Without	With
Without	18.35	16.59
With	16.70	16.25

c)

	EcoT	
B77	Without	With
Without	18.42	17.01
With	16.63	15.83

Table of non-significant means for *Cynodon dactylon* below ground biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	18.72	16.21
With	16.71	16.25

LSD $_{P=0.05}$= 1.23

b)

	EcoT	
B69	Without	With
Without	18.35	16.59
With	16.70	16.25

c)

	EcoT	
B77	Without	With
Without	18.42	17.01
With	16.63	15.83

Table of non-significant means for *Cynodon dactylon* total biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	24.04	20.56
With	20.17	19.93

LSD $_{P=0.05}$= 2.94

b)

	EcoT	
B69	Without	With
Without	22.47	22.14
With	20.21	19.90

c)

	EcoT	
B77	Without	With
Without	22.49	21.72
With	20.18	20.31

Table of non-significant means for *Cynodon dactylon* above ground: below ground biomass ratio two-way interactions.

a)

	B77	
B69	Without	With
Without	3.99	3.88
With	5.30	4.87

LSD $_{P=0.05}$= 1.55

b)

	EcoT	
B69	Without	With
Without	4.67	3.20
With	5.15	5.03

c)

	EcoT	
B77	Without	With
Without	4.91	4.39
With	4.19	3.84

Appendix 18

Non-significant means for trial M3, main effects

Table of non-significant means for *Themeda triandra* above ground biomass (g pot^{-1}) main effects.

a)

B77	
Without	With
14.51	14.42

LSD $_{P=0.05}$= 0.87

b)

EcoT	
Without	With
15.15	13.78

Table of means non-significant for *Themeda triandra* below ground biomass (g pot^{-1}) main effects.

a)

EcoT	
Without	With
12.88	11.53

LSD $_{P=0.05}$= 3.50

Table 24: Table of non-significant means for *Themeda triandra* total biomass (g pot^{-1}) main effects.

a)

B77	
Without	With
28.80	24.60

LSD $_{P=0.05}$= 4.19

b)

EcoT	
Without	With
28.00	25.30

Table 26: Table of non-significant means for *Themeda triandra* above ground: below ground biomass ratio main effects.

a)

B69	
Without	With
0.542	0.577

LSD $_{P=0.05}$= 0.09

b)

B77	
Without	With
0.519	0.601

c)

EcoT	
Without	With
0.548	0.572

Appendix 19

Non-significant means for trial M3, two-way interactions

Table of means non-significant for *Themeda triandra* above ground biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	14.82	17.23
With	14.21	11.60

LSD $_{P=0.05}$= 4.38

b)

	EcoT	
B69	Without	With
Without	16.38	15.66
With	13.91	11.90

c)

	EcoT	
B77	Without	With
Without	15.86	13.17
With	14.44	14.39

Table of non-significant means for *Themeda triandra* below ground biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	16.59	11.88
With	11.89	8.47

LSD $_{P=0.05}$= 4.94

b)

	EcoT	
B69	Without	With
Without	14.75	13.71
With	11.01	9.36

Table of non-significant means for *Themeda triandra* total biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	31.40	29.10
With	26.10	20.10

LSD $_{P=0.05}$= 5.9

b)

	EcoT	
B69	Without	With
Without	31.40	29.10
With	26.10	20.10

c)

	EcoT	
B77	Without	With
Without	31.10	21.40
With	24.90	21.30

Table of non-significant means for *Themeda triandra* above ground: below ground biomass ratio two-way interactions.

a)

	B77	
B69	Without	With
Without	0.495	0.59
With	0.543	0.611

LSD $_{P=0.05}$= 0.13

b)

	EcoT	
B69	Without	With
Without	0.532	0.552
With	0.563	0.591

Appendix 20

Non-significant means for trial M4, main effects

Table of non-significant means for *Cynodon dactylon* above biomass (g pot^{-1}) main effects.

a)

B69	
Without	With
26.48	25.70

LSD $_{P=0.05}$= 2.62

b)

B77	
Without	With
25.87	26.31

c)

EcoT	
Without	With
25.66	26.52

Table of non-significant means for *Cynodon dactylon* below biomass (g pot^{-1}) main effects.

a)

B69	
Without	With
3.71	3.88

LSD $_{P=0.05}$= 0.68

b)

B77	
Without	With
3.63	3.95

c)

EcoT	
Without	With
3.76	3.82

Table of non-significant means for *Cynodon dactylon* total biomass (g pot^{-1}) main effects.

a)

B69	
Without	With
30.19	29.58

LSD $_{P=0.05}$= 2.76

b)

B77	
Without	With
29.51	30.26

c)

EcoT	
Without	With
29.43	30.34

Table of non-significant means for *Cynodon dactylon* above ground: below ground biomass ratio main effects.

a)

B69	
Without	With
7.55	6.83

LSD $_{P=0.05}$= 1.42

b)

B77	
Without	With
7.22	7.16

c)

EcoT	
Without	With
7.13	7.25

Appendix 21

Non-significant means for trial M4, two-way interactions

Table of non-significant means for *Cynodon dactylon* above ground biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	26.14	26.82
With	25.61	25.79

LSD $_{P=0.05}$= 3.71

b)

	EcoT	
B69	Without	With
Without	26.13	26.83
With	25.20	26.20

c)

	EcoT	
B77	Without	With
Without	24.51	27.24
With	26.82	25.79

Table of non-significant means for *Cynodon dactylon* below ground biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	3.64	3.78
With	3.63	4.13

LSD $_{P=0.05}$= 0.96

b)

	EcoT	
B69	Without	With
Without	3.89	3.52
With	3.64	4.12

c)

	EcoT	
B77	Without	With
Without	3.51	3.75
With	4.01	3.89

Table of non-significant means for *Cynodon dactylon* total biomass (g pot^{-1}) two-way interactions.

a)

	B77	
B69	Without	With
Without	29.77	30.60
With	29.24	29.92

LSD $_{P=0.05}$= 3.908

b)

	EcoT	
B69	Without	With
Without	30.02	30.35
With	28.84	30.32

c)

	EcoT	
B77	Without	With
Without	28.02	30.99
With	30.83	29.68

Table of non-significant means for *Cynodon dactylon* above ground: below ground biomass ratio two-way interactions.

a)

	B77	
B69	Without	With
Without	7.38	7.71
With	7.06	6.61

LSD $_{P=0.05}$= 2.01

b)

	EcoT	
B69	Without	With
Without	7.12	7.97
With	7.14	6.53

c)

	EcoT	
B77	Without	With
Without	7.12	7.32
With	7.14	6.53

Appendix 22

Phosphorus application rate applications

Recommended rate:

1. 20 kg P ha^{-1}
2. 55 kg P ha^{-1}

Single super phosphate (10.5% P)

1. In 100 kg supers = 10.5 kg P

Therefore (20kg/ 10.5) x 100

= 190.4762 kg supers ha^{-1}

= (190.4762 kg supers ha^{-1}/ 10 000 m^2) x 1000 g/ 1 kg

= 19.0476 g m^2

Surface area of pot

$\prod r^2$

= 3.14 x $(0.12\ m)^2$

= 0.0452 m^2

Therefore the amount of supers per pot = 19.0476 g m^{-2} x 0.0452 m^2

= 0.869 g supers pot^{-1}

2. 55 kg P ha^{-1} required for the Syferfontein Mine soil applications= 0.673 g supers pot^{-1}

Appendix 23

Potassium application rate calculations

Recommended rate:

30 kg K ha^{-1}

KCl (50% K)

4. In 100 kg KCl = 50kg K

Therefore (30kg/ 50) x 100

= 60 kg KCl ha^{-1}

= (60 kg KCl. ha^{-1}/ 10 000 m^2) x 1000 g/1 kg

= 6 g m^2

Surface area of pot

$\prod r^2$

= 3.14 x $(0.12\ m)^2$

= 0.0452 m^2

Therefore the amount of KCl per pot = 6 g m^{-2} x 0.0314 m^2

= 0.271 g KCl pot^{-1}

Appendix 24

Non-significant means for Legume Trial, main effects

Table of non-significant means for *Themeda triandra* above ground biomass (g pot^{-1}) main effects.

a)

Potassium	
Without	With
2.06	2.31

LSD $_{P=0.05}$= 0.48

Table of non-significant means for *Themeda triandra* above ground biomass (g pot^{-1}) two-way interactions.

a)

	Phosphorus	
Legume	Without	With
Without	1.30b	2.88a
With	0.80b	1.28b

LSD $_{P=0.05}$= 0.68

b)

	Potassium	
Legume	Without	With
Without	2.49	2.92
With	1.62	1.69

c)

	Potassium	
Phosphorus	Without	With
Without	1.70	1.62
With	2.41	3.01

Appendix 25

Fly ash application rate calculation

Lime neutralizing value = 88.3%

Fly ash neutralizing value = 4.9%

Therefore 88.3/ 4.9 = 18.02041

Lime = 1 t ha^{-1}= 1000 kg ha^{-1}= 100 g m^{-2}

Fly ash = 18.020 t ha^{-1}= 18020.41 kg ha^{-1}=1802.041 g m^{-2}

Surface area of pot

$\prod r^2$

$= 3.14 \times (0.1 \text{ m})^2$

$= 0.0314 \text{ m}^2$

Therefore the amount of lime per pot = 100 g m^{-2} x 0.0314 m^2

= 3.14 g lime pot^{-1}

And the amount of fly ash per pot = 1802.041 g m^{-2} x 0.0314 m^2

= 56.584 g fly ash pot^{-1}

Appendix 26

Non-significant means for Fly Ash Trial, main effects and two-way interactions

Table of non-significant means for above ground biomass (g pot^{-1}) main effects.

a)

Fly ash	
Without	With
1.02	1.08

LSD $_{P=0.05}$= 0.62

b)

Lime	
Without	With
0.98	1.12

c)

Species	
Lucerne	*Themeda*
1.26	0.83

Table of non-significant means for above ground biomass (g pot^{-1}) two-way interactions.

a)

	Lime	
Fly ash	Without	With
Without	1.04	0.99
With	0.91	1.25

LSD $_{P=0.05}$= 0.88

b)

	Species	
Fly ash	Lucerne	*Themeda*
Without	1.18	0.85
With	1.35	0.81

c)

	Species	
Lime	Lucerne	*Themeda*
Without	1.04	0.91
With	1.49	0.75

Appendix 27

Non-significant means for Fly Ash Trial, main effects and two-way interactions

Table of non-significant means for below ground biomass (g pot^{-1}) main effects.

a)

Fly ash	
Without	With
0.601	0.814

LSD $_{P=0.05}$= 0.36

b)

Lime	
Without	With
0.678	0.736

c)

Species	
Lucerne	*Themeda*
0.839	0.576

Table of non-significant means for below ground biomass (g pot^{-1}) two-way interactions.

a)

	Lime	
Fly ash	Without	With
Without	0.596	0.605
With	0.760	0.867

LSD $_{P=0.05}$= 0.51

b)

	Species	
Fly ash	Lucerne	*Themeda*
Without	0.617	0.584
With	1.060	0.57

c)

	Species	
Lime	Lucerne	*Themeda*
Without	0.787	0.569
With	0.890	0.583

Appendix 28

Non-significant means for Fly Ash Trial, main effects and two-way interactions

Table of non-significant means for total biomass (g pot^{-1}) main effects.

a)

Fly ash	
Without	With
1.62	1.89

LSD $_{P=0.05}$= 0.90

b)

Lime	
Without	With
1.65	1.86

c)

Species	
Lucerne	*Themeda*
2.10	1.41

Table of non-significant means for total biomass (g pot^{-1}) two-way interactions.

a)

	Lime	
Fly ash	Without	With
Without	1.64	1.60
With	1.67	2.12

LSD $_{P=0.05}$= 1.27

b)

	Species	
Fly ash	Lucerne	*Themeda*
Without	1.80	1.44
With	2.41	1.38

c)

	Species	
Lime	Lucerne	*Themeda*
Without	1.83	1.48
With	2.38	1.33

Appendix 29

Non-significant means for Fly Ash Trial, main effects and two way interactions

Table of non-significant means for above ground: below ground biomass ratio main effects.

a)

Fly ash	
Without	With
1.560	1.537

LSD $_{P=0.05}$= 0.40

b)

Lime	
Without	With
1.513	1.584

c)

Species	
Lucerne	*Themeda*
1.68	1.421

Table of non-significant means for above ground: below ground biomass ratio two-way interactions.

a)

	Lime	
Fly ash	Without	With
Without	1.617	1.502
With	1.410	1.665

LSD $_{P=0.05}$= 0.57

b)

	Species	
Fly ash	Lucerne	*Themeda*
Without	1.777	1.342
With	1.575	1.500

c)

	Species	
Lime	Lucerne	*Themeda*
Without	1.516	1.511
With	1.836	1.331

Appendix 30

Non-significant means for initial Fly Ash Trial soil pH, main effects and two-way interactions

Table of non-significant means for initial soil pH main effects.

a)

Species	
Lucerne	*Themeda*
5.930	6.121

LSD $_{P=0.05}$= 0.31

Table of non-significant means for initial soil pH two-way interactions.

a)

	Lime	
Fly ash	Without	With
Without	4.460	4.540
With	4.430	4.646

LSD $_{P=0.05}$= 0.43

b)

	Species	
Fly ash	Lucerne	*Themeda*
Without	4.409	4.591
With	4.444	4.632

c)

	Species	
Lime	Lucerne	*Themeda*
Without	4.389	4.501
With	4.464	4.722

Appendix 31

Non-significant means for final Fly Ash Trial soil pH, main effects and two-way interactions

Table of non-significant means for final soil pH main effects.

a)

Fly ash	
Without	With
4.500	4.538

LSD $_{P=0.05}$= 0.31

b)

Lime	
Without	With
4.445	4.593

c)

Species	
Lucerne	*Themeda*
4.426	4.612

Table of non-significant means for final soil pH two-way interactions.

a)

	Lime	
Fly ash	Without	With
Without	4.460	4.540
With	4.430	4.646

LSD $_{P=0.05}$= 0.34

b)

	Species	
Fly ash	Lucerne	*Themeda*
Without	4.409	4.591
With	4.444	4.632

c)

	Species	
Lime	Lucerne	*Themeda*
Without	4.389	4.501
With	4.464	4.722

Appendix 32

Initial and final Fly Ash Trial soil pH

Initial and final soil pH results with various treatments.

Repetition	Species	Fly ash	Lime	Initial pH	Final pH
R1	Lucerne	Without	Without	5.62	4.41
R1	Lucerne	Without	With	5.93	4.23
R1	Lucerne	With	Without	6.42	4.27
R1	Lucerne	With	With	6.26	4.28
R1	Themeda	Without	Without	5.50	4.40
R1	Themeda	Without	With	5.18	4.30
R1	Themeda	With	Without	6.31	4.38
R1	Themeda	With	With	6.79	4.43
R2	Lucerne	Without	Without	4.76	4.41
R2	Lucerne	Without	With	6.01	4.33
R2	Lucerne	With	Without	6.05	4.17
R2	Lucerne	With	With	6.47	4.46
R2	Themeda	Without	Without	5.35	4.60
R2	Themeda	Without	With	6.32	4.21
R2	Themeda	With	Without	6.49	4.32
R2	Themeda	With	With	6.70	5.54
R3	Lucerne	Without	Without	4.96	4.42
R3	Lucerne	Without	With	6.01	4.49
R3	Lucerne	With	Without	6.17	4.38
R3	Lucerne	With	With	6.89	5.10
R3	Themeda	Without	Without	4.36	4.36
R3	Themeda	Without	With	6.36	5.57
R3	Themeda	With	Without	6.87	4.77
R3	Themeda	With	With	6.94	4.43
R4	Lucerne	Without	Without	4.18	4.52
R4	Lucerne	Without	With	5.77	4.46
R4	Lucerne	With	Without	6.84	4.53
R4	Lucerne	With	With	6.54	4.36
R4	Themeda	Without	Without	5.10	4.56
R4	Themeda	Without	With	6.10	4.73
R4	Themeda	With	Without	6.88	4.62
R4	Themeda	With	With	6.69	4.57

Initial and final soil pH values from two pots containing fertilizer along with lime or fly ash, but no *Themeda triandra* or lucerne was grown.

Treatment	Initial pH	Final pH
Lime	6.01	5.64
Fly ash	6.37	5.81