THE ASSESSMENT OF TOPSOIL DEGRADATION ON REHABILITATED COAL DISCARD DUMPS

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Summary

This study investigates coal discard cover soil fertility and its potential for degradation, particularly in terms of its salinisation and acidification potential. Seven rehabilitated coal discard dumps in the Witbank, Ermelo and Newcastle regions were used as study areas. All areas were rehabilitated with a cover soil layer, revegetated and annually fertilised with nitrate fertilisers, super phosphate, kraal manure and lime. Performance guideline for pH of 5.5-(6.5 ±0.5)-7.5 and electrical conductivity guideline of preferably less than 200 mS.m^{-1} but not higher than 400 mS.m^{-1} were set based on literature information. Soil chemical data from a three-year fertilisation programme were used to assess the fertility of the cover soil surface (0-150mm). Data collected over a three year period as well as additional electrical conductivity and pH measurements from the cover soil surface, subsoil, cover soil/coal contact zone and underlying coal itself were used to assess the occurrence of salinisation and acidification of the cover soil. The soil fertility varied significantly among dumps as well as over the three years. Results indicated an increase in ammonium acetate extractable macro elements (calcium, magnesium and potassium). With the exception of manganese, no micro-element toxicities were recorded. Iron concentrations were slightly elevated in some of the sandy cover soil layers. No increase in soluble nitrogen (nitrate and ammonium) was found and most soluble nitrogen was in the form of nitrates. In general the Bray extractable phosphate increased during the study period. It can be predicted that with the following fertiliser programme increases of exchangeable macro-elements as well as available phosphorus can be expected. The study could not indicate an increase in adsorbed or available nitrogen. Organic carbon was initially not analysed therefore no comments can be made whether organic matter increased. Four of the seven dumps surveyed had comparably similar organic carbon levels to the background samples. Overall the fertiliser programme increased the electrical conductivity and decreased the acidity of the cover soil surface. Acidity and salinity was in general not a problem at the surface of the cover soil and pH was even slightly higher in cover soil samples. The acidity and especially salinity increased at the subsoil and so did the sulphate concentrations. Calcium and magnesium sulphate were predominantly responsible for higher electrical conductivity measurements. The percentage exchangeable sodium was also predominantly less than 2% indicating that sodicity is not currently a problem in cover soil. Soil fertility was satisfactory for vegetation growth and macro-

element concentrations were in the correct ratio although calcium was slightly high. An elevated sulphate concentration, in comparison to the natural grassland soils, as well as a high salinity and high acidity in the subsoil layers indicate that salinisation and acidification could deteriorate without proper management. A slightly acidic cover soil can also be attributed partially to its natural acidic pH due to the well-weathered and leach property of burrow pit. Higher than recommended salinity levels were found in subsoil samples but the occurrence of acidification of the subsoil was more dump specific. In relation to acidity and salinity guidelines only the cover soil of one dump was concerning and the larger dumps subsoil acidity and salinity were elevated.

The following management strategies are proposed:

a) The acidification potential, and therefore the pyrite content of the coal discard must be considered during decisions making on the rehabilitation method (clay barriers), topsoil depth, maintenance and mine closure potential.

b) The occasional monitoring of the subsoil's and coal contact acidity is recommended, although not much can be done to stop acidification after cover-soil placement.

c) To ensure a more sustained from of nitrogen supplementation over the long term the use of selected legumes should be investigated. Research in Europe and Australia suggested that nitrogen fixation could contribute substantially to the nitrogen for plant uptake.

d) The physical properties of the topsoil (bulk density & soil compaction) are also being neglected and needs to be assessed occasionally and interpreted together with chemical analyses. Observations in other studies indicate that this could be the most fundamental problem for vegetation growth and not necessarily soil fertility, since soil physical properties could have a major impact on root development.

Key words: Coal discard, mine rehabilitation, soil fertility, topsoil degradation, salinisation, and acidification

Opsomming

Die studie ondersoek die grondvrugbaarheid en potensiaal vir chemiese degradasie met spefisieke klem op versouting en versuring van deklaaggrond op gerehabiliteerde steenkooluitskothope. Die studie is onderneem op sewe uitskothope in die Witbank, Ermelo en Newcastle omgewing. Die sewe uitskothope was gerehabiliteer met 'n deklaag van bogrond en daarna begras. Die plantegroei wat daarop gevestig is, is jaarlike onderhou deur bemesting met nitraat-bevattende misstowwe, superfosfaat, kraalmis en kalk. Riglyne volgens literatuur dui daarop dat grond pH binne die riglyn van 5.5-(6.5 ±0.5)-7.5 moet val en elektriese geleiding verkieslik laer as 200 $mS.m^{-1}$, maar nie hoër as 400 $mS.m^{-1}$ mag wees nie. Grondchemiese data, geneem tydens 'n drie jaar bemestingsprogram, is gebruik om die vrugbaarheid van die deklaagoppervlak te bepaal. Dieselfde datastel, asook addisionele elektriesegeleiding en pH data van die deklaag oppervlak, ondergrond, grond-steenkool kontaklaag en steenkooluitskot is gebruik om die voorkoms van versouting en versuring in die deklaag te kwantifiseer. Grondvrugbaarheid op die gerehabiliteerde uitskothope was kenmerkend wisselvalig. Ammonium ekstraheerbare makro-elemente het oor die studietydperk toegeneem. Met die uitsondering van mangaan het geen phytovergiftiging van mikro-element voorgekom nie. Die wateroplosbare yster konsentrasies was in sommige sanderige deklae effe hoog. Oplosbare stikstof het oor die drie jaar periode dieselfde gebly en het hoofsaaklik as nitraat voorgekom. Die Bray ekstraheerbare fosfor het gedurende die studietyperk toegeneem. Resultate dui daarop dat die huidig bemestingprogramme die uitruilbare makro-elemente en die Bray ekstraheerbare fosfor verhoog het. Geen uitspraak kan gegee word of die huidige bemesting die organiese inhoud van die grond verhoog het nie. Sommige uitskothope het egter 'n vergelykbare organiese inhoud gehad as wat in onversteurde grond gemeet is. Oor die algemeen het die bemesting program die elektriesegeleiding van die deklaag verhoog asook die bestaande suur potensiaal geneutraliseer. As gevolg van gereelde bekalking van die deklaag was versuring nie 'n probleem nie en die pH was in sommige gevalle effe hoër as data van natuurlike grond. Oppervlak monsters van die deklaag het nie werklik 'n versoutings probleem uitgewys nie. Die deklaag het egter versuur en versout nagelang dit met die steenkooluitskot in aanraking gekom het. Soute en sure het ook, gepaartgegaan met 'n toename in oplosbare sulfaat, toegeneem. Hoër elektriesegeleiding waardes kon direk inverband gebring word met sulfaat konsentrasies. Die persentasie uitruilbare natruim was oorwegend minder as 1% en alkali toestande bestaan nie huidiglik in die gronddeklaag nie. Chemiese analises

van die gronddeklaagoppervlak dui op gunstige groeitoestande. Die potensiaal vir versouting en versuring bestaan egter met die afwesigheid van korrekte bestuur as die hoër sulfaatvlakke, hoër soute en laer pH van die ondergrond op die uitskothope in aanmerking geneem word. Grond in die omgewing is egter van nature suur as gevolg van gevordere verwering en loging. Dit gee aanleiding dat die deklaag inherent suur is en die potensiaal het om natuurlik weer te versuur. Alhoewel die ondergrond redelik versout het in alle uitskothope was versuring tot die groter hope beperk. Ten opsigte van vasgestelde elektriesegeleiding en pH riglyne was net een uitskothoop nie bevredigend nie en het drie hope se ondergrond, wat in kontak met die steenkool is, die suur en versoutings riglyne oorskry.

Die volgende bestuursriglyne en praktyke word voorgestel:

e) Soos in literatuur genoem is pirietoksidasie een van die mees bepalende faktore wat die rehabiliteringsmetode, diepte van die deklaag, onderhoud en finale sluiting van die myn sal beïnvloed.

f) Die potensiaal van peulgewasse om 'n volhoubare bron van stikstof te verseker moet ondersoek word. Navorsing in Europa en Australië dui daarop dat stikstoffikserende bakterieë 'n redelike langtermyn bydra tot beskikbare grondstikstof mag hê.

g) Die dokument stel ook moniteringskriteria voor om die grondvrugbaarheid korrek te bestuur. Die bepaling van die suurheid van die ondergrond en steenkool word per geleentheid, soos met die verandering van bestuursstrategieë of voor mynsluiting aanbeveel. Nie veel kan egter ekonomies aan 'n versurende ondergrond en steenkool gedoen word sodra bogrond geplaas is nie.

h) Tot op hede is die grondfisiese eienskappe soos brutodigtheid en kompaksie nie ondersoek nie alhoewel waarnemings dit as 'n potensiële probleem aangedui het. Grondfisiese probleme is soms meer fundamenteel en het 'n groter invloed op plantvestiging as die bron van nutriente.

Sleutelwoorde: Steenkooluitskot, mynrehabilitasie, grondfertiliteit, deklaag degradasie, versouting, versuring

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1. INTRODUCTION

South Africa is the largest producer of coal in Africa and holds 11% of the worlds coal reserves (Walton, 1984). Coal is found in South Africa as far south as Molteno and as far north as Mussina (Walton, 1984). Most coal mines are concentrated in four coal producing belts in South Africa namely the Mpumalanga Highveld around the towns of Witbank to Ermelo, Northern Transvaal, Northern Free State near the town of Sasolburg and Natal Midlands stretching from Newcastle to Vryheid. Open-cast coal mining activities are leaving an unmistakable footprint on the landscape in the form of altering landscapes form due to open-cast operations, land subsistence from pillar mining and the creation of discard dumps. Valuable agricultural land is being degraded and the long-term productivity of the land is therefore affected. As part of colliery operations, coal discard and slimes are produced during the washing and sorting of coal. This study specifically focuses on discard dumps created by colliery operations.

Opencast pits can be aesthetically improved through backfilling, placement of topsoil layer and proper sloping and revegetation practices. Unfortunately related discard dumps associated with collieries are difficult to integrate into the gentle landscapes of the Witbank area (Bell *et al.*, 2001). This is mostly due to its steep slopes and dissimilar topography. A dedicated attempt is therefore required by coal mining companies to manage environmental impacts and properly rehabilitate discard dumps.

Smyth and Dearden (1998a) found a preoccupation with sort-term economic goals in the Canadian mining sector when it comes to environmental issues and sustainable development. The need for considering the long-term impact of mining operations is therefore sadly neglected. Industry and government engineers in Canada also had different opinions on issues of performance criteria for mine rehabilitation and bond release (Smyth and Dearden, 1998a). A lack of consensus on technical issues therefore existed between sectors and even between states. Polarisation in opinions among rehabilitation practitioners, industry and government has also been observed by Smyth and Dearden (1998a) and their opinions are that this can have a serious consequence on the implementation of regulatory programmes and the success to rehabilitate disturbances. The question can be asked to what extent does this tendency, exist among mining company directors, mine engineering contractors and environmental consultants in South Africa?

Operationally mine rehabilitation is most often planned around the mining activity and at the end during decommissioning. A more sustainable approach would have been to conduct the mining activities around the rehabilitation process so that mining and rehabilitation occur concurrently and simultaneously (EPA, 1995). The minerals Act no 50 of 1991 (South Africa, 1991) aimed to achieve this since section 38 (a) and (b) required that rehabilitation be conducted as an integral part of mining operations and be conducted simultaneous with such activities. A further problem with mine rehabilitation is the implementation of scientific knowledge gained by local and international rehabilitation research. Although mining industry does sponsor research, they do not implement knowledge gained from it. A good example of this is the research of Van Wyk (1994) who unequivocally indicated that without proper sloping any sustainable rehabilitation would be impossible. Internationally consensus exists on the potential problems associated with the rehabilitation of mine land and extensive reviews on this topic have been published by Bradshaw and Chadwick (1980) and Wali (1999). In the South African Chamber of Mines have published two sets of guidelines for the rehabilitation of coal-mines. Efforts are being made to upgrade the guidelines of which one is specially dedicated to the rehabilitation of discard dumps. Mentis (1999b) and Limpitlaw et al. (1997) have also set standards for the evaluation of rehabilitation practices.

A few publications regarding the rehabilitation of coal spoil or discard have been published internationally. Most of these studies are relatively old and many originated around the 1980's with the implementation of the American Surface Mining Control and Reclamation Act of 1977. Problems as well as principles for successful rehabilitation are therefore relatively old. Schaller and Sutton (1978) gave information on aspects such as erosion control, fertilisation of rehabilitated land, acid mine drainage, physical and chemical characteristics of overburden, the use of mulches, fertilisers, sewage sludge and fly ash. Studies relating to coal mine rehabilitation were focused around the rehabilitation of open cast mining areas. Some recent research (1990 to current) results have been published from Australia, especially in the Australian Journal of Soil Research. A study relevant to this study is that of Brown and Grant (2000) whom investigated the nutrient status of pastures on rehabilitated overburden. Experimental studies on mine rehabilitation in general and pollution are also published in the Journal of Environmental Quality, Ecological Engineering and Restoration Ecology as well as a variety of other publications relevant to the fields of botany, geography, geology and microbiology.

Bell (1996) discussed a case study on the rehabilitation of two old colliery spoil heaps (29.5 and 25 ha) in Yorkshire England. According to Bell (1996) the biggest concern when rehabilitating colliery spoil heaps are grading, acidity and spontaneous combustion due to exothermic reactions. A study by Taylor and Spear (1972) indicated that the oxidation of pyrite does not extent beyond a meter but that pyrite breakdown and weathering can be as deep as 3m. The oxidation of pyrite and acidification in spoil heaps is well studied and well discussed (Backes et al., 1986; Kent, 1982 and Bell, 1996). According to Backes et al. (1986) pyrite oxidation occurs via two pathways, either through the addition of oxygen or ferric ions. Backes et al. (1986) further indicates that pH and the solubility of iron play an important role in governing acid release. Below a pH of 4 ferrous ions are bacterially catalysed to ferric ions. The reaction results in the accelerated oxidation of pyrite. According to Kent (1982) it is recommended to investigate the carbonate /pyrite ratio to determine the natural neutralisation potential of the material when rehabilitating coal spoils material such as discard. In South Africa most of the problems of rehabilitating coal discard or open-cast areas are associated with acid mine drainage due to a high pyrite content in coal (Bell et al., 2001). The pyrite content, however, varies among mines depending on the locality of the mine and the seams being mined.

De and Mitra (2002) published result from a study describing the direct reclamation of open-cast mining spoils in eastern India with a variety of trees, shrubs and forbs during a period of five year. De and Mitra (2002) noted a steady rise in pH, macronutrients, organic carbon and cation exchange capacity during his study of rehabilitated open cast areas in India. The growth medium/spoil was characteristically acidic (pH $\approx$ 5.5) and slightly saline (EC $\approx$ 200 mS.m^{-1}). Recent research in Australia has investigated changes in the physical properties of topsoil (Loch and Orange, 2000), litter cover as an indication of nitrogen availability (Todd et al., 2000) as well as the general nutrient status of rehabilitated opencast areas (Brown & Grant, 2000) among other subjects. Research on mine rehabilitation therefore still remains an active science in many countries where mining are conducted.

Although experiments on mine rehabilitation have been conducted by industry in South Africa, very little of these have been published mainly due to three reasons. The results of trials are used for commercial purposes and are seen as trade secrets, have been conducted informally without sufficient replicates, or are too sensitive to

publish as it could create legal liabilities. Most of the available literature is in the form of congress abstracts or proceedings. Rethman and Tanner (1993) presented a paper on the influence of topsoil fertility on botanical composition of rehabilitated pastures at the National Congress of the American Society for Strip Mining and Reclamation. Rethman and Tanner (1995) also presented a second paper on grassland sustainability on rehabilitated opencast coal lands at the Conference on Mining and the Environment in Sudbury, USA. At the IBC conference in 1998 in Pretoria, Aken (1998) and Tanner (1998) presented papers on issues of soil handling and rehabilitation philosophy when rehabilitating coal-mining area. Probably the most recent publication relating to rehabilitating coal mining areas and the environmental management of coal mining areas is that of Mentis (1999a) and Bell *et al.* (2001). A number of research projects from the Water Research Council also relate to rehabilitating coal-mining areas.

1.1.   Study Aim and objectives

The study was conducted on seven discard dumps that was rehabilitated and managed by Ingwe Mine Closure Operations. Ingwe is the second largest operating coal-mining corporation in South Africa and has six collieries in operation, which have reserves of 1424 million ton of recoverable coal reserves (BHPbilliton, 2002). The rehabilitated dumps used in this study were inherited from amalgamations with other smaller operators and have mostly been non-operational collieries.

A mine closure section of a coal-mining company has conducted an intensive fertilisation programme on seven discard dumps for the past three years to ensure the development of a self-sustaining vegetation cover for mine closure as specified under the South African Minerals Act no 50 of 1989

The objective of the study was:

To make a statement on the quality and occurrence of chemical degradation of topsoil on seven rehabilitated discard dumps for effective vegetation growth in terms of:

Evaluating the cover soil fertility of seven managed rehabilitated discard dumps in comparison to background soil samples and comparable soil fertility guidelines.

Assessing the occurrence of salinisation and acidification in the cover soil layers of seven managed rehabilitated discard dumps.

The mini dissertation is structured into four chapters. The first chapter gives an introduction to the environmental problems surrounding coal-mine rehabilitation and current trends in research. The chapter highlights the legislative requirements of coal-mine rehabilitation and investigates performance criteria for soil fertility. Based on available literature, chapter one sets performance criteria for salinity and acidity that will be used in chapter four to audit the present occurrence of salinity and acidity

in cover soil. Chapter two and three were written as independent articles that will be submitted for publication in peer-reviewed journals. Chapter 2 gives an introduction to the study area; maintenance practices used and discuss the results from a three-year soil fertility monitoring/maintenance programme. Chapter 3 deals more specifically with the issue of cover soil salinity and acidity. Chapter 4 includes an audit of the current acidity and salinity of the cover soil surface and subsoil. The chapter critically evaluates the methods used for analysing the cover soil samples and the fertilisers used. Chapter 4 concludes the study with a short management strategy for evaluating soil salinity and acidity in cover soil.

1.2. Environmental Regulations relating to coal mining

1.2.1. South Africa

The regulating and management of environmental impacts in South Africa, until 2002, has presided under the jurisdiction of the Minerals Act no. 50 of 1991 (South Africa, 1991). This act required prospecting mining companies to submit an Environmental Management Programme (EMP) containing baseline information, impact assessments, and mitigation measures for each stage during the commissioning, operating and decommissioning of the mine. The EMP would indicate how the mine would rehabilitate disturbances caused by operations. These environmental objectives would then be used to grant mine closure if all requirements were met. Mining companies were also obligated to rehabilitate disturbances caused by operations. Rehabilitation is defined in South African regulations as: " *in relation to the surface of land and the environment, the execution by the holder of a prospecting permit or mining authorisation of the environmental management programme referred to section 39 to the satisfaction of the Director: Mineral Development*" (South Africa, 1991). The only guidelines given under the Minerals Act for mine rehabilitation are that they must be according to the EMP, be an integral part of prospecting or mining, must occur simultaneously with mine operations and must be conducted to the satisfaction of the Director Minerals Development (South Africa, 1991).

Under the new Mineral and Petroleum Resources Development Act no 28 of 2002 (South Africa, 2002) all environmental issues will be integrated with the principles set out under the National Environmental Management Act (act 107 of 1998).

In short the act gives the following directives for the rehabilitation of land:

37. (1) The principles set out in section 2 of the National Environmental Management Act, 1998 (Act No.107 of 1998) (a) apply to all prospecting and mining operations, as the case may be, and any matter relating to such operation; and (b) serve as guidelines for the interpretation, administration and implementation of the environmental requirements of this Act.

38. (1) The holder of a reconnaissance permission, prospecting right, mining right, mining permit or retention permit (b) must consider, investigate, assess and communicate the impact of his or her prospecting or mining on the environment as contemplated in section 24(7) of the National Environmental Management Act, 1998 (Act No. 107 of 1998); (c) must manage all environmental impacts (i) in accordance with his or her environmental management plan or approved environmental management programme, where appropriate; and (ii) as an integral part of the reconnaissance, prospecting or mining operation, unless the Minister directs otherwise; (d) must as far as it is reasonably practicable, rehabilitate the environment affected by the prospecting or mining operations to its natural or predetermined state or to a land use which conforms to the generally accepted principle of sustainable development; and (e) is responsible for any environmental damage, pollution or ecological degradation as a result of his or her reconnaissance prospecting or mining operations and which may occur inside and outside the boundaries of the area to which such right, permit or permission relates.

41. (1) An applicant for a prospecting right, mining right or mining permit must, before the Minister approves the environmental management plan or environmental management programme in terms of section 39(4), make the prescribed financial provision for the rehabilitation or management of negative environmental impacts.

43. (1) The holder of a prospecting right, mining right, retention permit or mining permit remains responsible for any environmental liability, pollution or ecological degradation, and the management thereof, until the Minister has issued a closure certificate to the holder concerned.

1.2.2. United States of America

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) principally protects environmental interests in the mining industry in America (Sandoval and Power 1977). The act relates specifically to open-cast coal mining operations, the manner in which environmental impacts need to be accounted for, the provision for bond and bond release and reclamation standards. The act empowers states to establish their own regulations under this act. The Surface Mining and reclamation act of 1977 primarily differs, among other aspects, from the South African Minerals and Petroleum Resources Development Act 28 of 2002 in that it gives detailed information and environmental standards for the mining, rehabilitation and bond release. The legislation therefore sets minimum performance standards for further detail regulations from state departments. Essentially section 515 of SMCRA

provides Environmental Protection Performance Standards and requires among other's that reclamation practices:

"Restore the land affected to a condition capable of supporting the uses, which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood, so long as such use or uses do not present any actual or probable hazard to public health or safety or pose any actual or probable threat of water diminution or pollution, and the permit applicants' declared proposed land use following reclamation is not deemed to be impractical or unreasonable, inconsistent with applicable land use policies and plans, involves unreasonable delay in implementation, or is violative of Federal, State, or local law;"

The act gives directives on aspects on reclamation such as the handling of acid forming materials; the sloping and landscaping of mine areas; the removal, segregation and replacement of topsoil, the revegetation of mining areas and hydrology (Imes and Wali, 1978). The act requires that the mining operator will remain responsible for revegetation for a period of at least five years or 10 years where precipitation is less than 660mm.

Good examples of state generated regulations; rules and guidelines relating to mine reclamation, are those published by the Wyoming State Department (see http://deq.state.wy.us/lqd.htm for detail on guideline documents. Specifications and guidelines used by the Wyoming State Department will be discussed later in the chapter. Federal regulations stipulate that rules and regulations must be implemented to judge the success of the vegetation establishment and to achieve that standards for success and statistically valid sampling techniques for measuring success shall be developed.

1.2.3. Australia

An overview of Australian legislation indicates that environmental legislation relating to mining follows a similar framework of decentralisation in legislative authority than is the situation in the USA. Each state within the Commonwealth therefore regulates its own mining activities. In Queensland the Environmental Protection and Other Legislation Amendment Act no. 64 of 2000 was implemented to redirect environmental issues relating to mining from the Mineral Resource Act of 1989 to the Environmental Protection Act of 1994. Most environmental issues relating to mining

are therefore dealt with under this act in Queensland. Environmental issues related to mining in the Victoria Government as far as can be established are mostly governed by the Mineral Resource and Development Act of 1990 (State of Victoria, 2002). In general it seems that environmental legislation in Australia, as is the case in South Africa, does not directly indicate standards or performance indicators. General guidelines for rehabilitation are published in advisory guideline documents (EPA, 1995). Documents are also available indicating bond requirements and how to calculate bonds for rehabilitation (Anon, 1997). The Government of Victoria has a guideline document available through the World Wide Web giving guidance on rehabilitation plans and other environmental aspects (State of Victoria, 2002). The guidance document (State of Victoria, 2002) states that monitoring and maintenance schedules as well as objectives and criteria pertaining to mine rehabilitation must be stipulated within the Rehabilitation Plan.

1.2.4. Company self regulation

Many international companies have gone beyond government regulatory compliance and have made there own commitments regarding the manner they manage environmental impacts. Companies are more often taking responsibility for their own impacts. BHPbilliton, the holder companies of INGWE, that are currently responsible for the dumps studied have made the commitment to "progressively reduce impacts and the consequent risk or harm and achieve overall improvements in environmental performance" (BHPbilliton, 2002). Under an ISO140001 system the company will have the responsibility to commit to their environmental policy and environmental management plan (SABS, 1996).

1.3. Soil performance guidelines and there measurement

As already indicated legislation is available to manage rehabilitation processes but it does not always give directives on the standards of the rehabilitation process or the success criteria that can be used. Available literature, however, can be used as directives. The identification of rehabilitation success criteria and measurement of rehabilitation success is in it self a challenging exercise (Haigh, 1998). Success criteria must be able to be scientifically rigorous and satisfy a broad spectrum of stakeholders and be informative to decision-makers. The evaluation programme must consider the post-mine land use, the characteristics of the reclaimed land, the

criteria to be used and the method that will be used to evaluate the rehabilitated land against success criteria (Ries and Hofmann, 1984).

Currently a weighted scoring system is used to evaluate the rehabilitated areas used in this study, based on land capability, erosion potential, landscape form, soil fertility, species composition, pasture structure and forage quality (crude protein). With regard to soil fertility the assessment method includes phosphorus, potassium, zinc and acid saturation and soil organic carbon (Mentis 1999b).

An alternative is to obtain data from representative reference sites after scientifically scrutinising reference sites (Short *et al.*, 2000). Candidate indicators are chosen as measurable representatives of function. References sites are selected based on their coefficient of variance (CV). Success ratios are then compared with success criteria within a yardstick of achievement (Short *et al.*, 2000). The use of reference sites can, however, be intricate since the growth medium on rehabilitated land is difficult to compare with natural soils; natural undisturbed, unfertilised soils of the same soil type are not always available and the quality of the original soils used is unknown. This study will use reference sites for comparison, but due to limited sampling of reference sites no site selection for reference sites will be conducted.

A potential method to investigate topsoil quality is by regression analysis to relate soil properties to biomass production in a predictive reclamation model. Burley *et al.* (1989) used this method to develop productivity equations for reclaimed open-cast areas. Burley *et al.* (1989) was able to relate hydraulic conductivity, slope steepness, soil bulk density, percentage rock fragments electrical conductivity and organic matter to plant production. Their study therefore indicated the importance of soil physical properties together with soil salinity as success criteria.

1.3.1. The measurement and use of performance standards

The importance of performance or success criteria within a regulatory framework is clearly illustrated by Smyth and Dearden (1998b). Performance standards must be regarded as:" *regulatory criteria used to indicate reclamation success or failure and to ensure that long-term environmental degradation is minimized or eliminated*" Smyth and Dearden (1998b). These performance standards are used in a monitoring system to provide feedback to ensure that environmental management systems is sufficient to mitigate impacts on endpoint uses, ecosystems and landscapes (Smyth and

Dearden, 1998b). Without performance standards, bond release/ mine closure is subjective and could be a liability to the state and end user.

Schafer (1979) provided guidelines for this purpose based on USA land capability classifications. Some soil quality guidelines indicated by Schafer (1979) includes soil texture, moist consistency, electrical conductivity, exchangeable sodium percentage (ESP), pH, stoniness, available water, % rock fragments and saturated water percentage. A useful book to be used for mine site rehabilitation was written by Williamson *et al.* (1982). Although Williamson *et al.* (1982) compiled the book to give guidance on the rehabilitation of mine waste it also indicates benchmark values to determine phyto-toxicity, salinity, acidity/alkalinity or general nutrient problems. Under the Surface Mining Control and Reclamation Act of 1977 American States have also set guideline documents for mining to ensure proper topsoil management. A good example of this is the Wyoming Department of Environmental Quality guideline document on topsoil and overburden use (Wyoming Department of Environmental Quality, 1994). The document gives specific directives for topsoil assessment including standards for acid base accounting and soil fertility assessments. The guideline mostly uses methods described in the USDA Handbook volumes 18 and 60 as well as the American Society of Agronomy Monographs (Wyoming Department of Environmental Quality, 1994). Haigh (1998) proposes the use of only two soil quality standards; bulk density and pH. General fertility guidelines for vegetation growth are often provided in soil fertility handbooks for example by Cummings and Elliott (1991), Havlin *et al.* (1999) and Mengel and Kirby (1987). The shortcoming when using these sources is that critical values have been determined from a variety of methods and have been set for intensive agricultural purposes where production is critical. An alternative method is to test rehabilitated sites against soil fertility indices derived from multivariate analyses such as factor analysis (Paniagua *et al.*, 1999). In South Africa Limpitlaw *et al.* (1997) and Mentis (1999b) have set some guidelines on the auditing of open cast areas with regard to landscape quality and soil fertility. Landscape quality is based on the soil loss hazard or erosion potential and landscape form whereas soil fertility assesses the levels of nitrogen, phosphate and acidity in the soil. Probably the earliest guidelines on coal mining rehabilitation were by the Chamber of Mines (1981). These guidelines also give directives for fertilisation in terms of nitrogen, phosphorus, potassium and magnesium.

A large source of methods for estimating cover soil fertility has been written. Probably some of the earliest works in this regard are by Sandoval and Power (1977) and Berg (1978). A similar comprehensive guide for opencast mining was published by Hossner (1980) and Bradshaw and Chadwick (1980) for the reclamation of surface mine land.

1.3.2. Salinity

Generally three salinity conditions are recognised: saline, sodic/alkali and saline-sodic. The existence of such conditions is generally determined based on salt concentrations measured as electrical conductivity, sodium concentration in relation to the exchangeable calcium and magnesium content in the soil (alternatively known as the Exchangeable Sodium Percentage (ESP)) and the soil pH.

Saline soils have a saturated extract conductivity (EC) of 400 mSm^{-1}, a pH of less than 8.5 and an ESP of 15%. Most of the salts are in the form of Cl, SO_4, HCO_3 or CO_3.

Sodic soils have an EC less than 400 mSm^{-1} but an ESP greater than 15%. The pH is frequently higher than 8.5 in sodic soils.

A sodic saline soil has both a high salt concentration (EC> $400mSm^{-1}$) and an ESP higher than 15%.

Although an electrical conductivity higher than $400mS.m^{-1}$ is regarded as saline, plant production can be effected at much lower salt concentrations. Red clovers and *Eragrostis curvula* (Love grass) productivity can for example already be reduced at electrical conductivity values higher than 200 $mS.m^{-1}$ (Havlin *et al.*, 2002). A species such as *Chloris gayana* (Rhodes grass) is regarded tolerant to salinity and only decrease in productivity at electrical conductivity values of $900mSm^{-1}$ and higher (Buys, 1986).

The guideline in this study is that the saturated pastes electrical conductivity of the topsoil must preferably be **lower than 200 mS.m^{-1}** and must **not exceed 400 mS.m^{-1}**. This guideline is in line with the electrical conductivity value specified by Williamson *et al.* (1982) and Cummings and Elliott (1991) for normal plant growth. Typical grass species indicated as tolerant for saline conditions include *Cynodon*

dactylon and *Chloris gayana* (Cummings & Elliott, 1991) and may grow under more extreme salinity values.

1.3.3. Acidity

Although acidity seems straightforward, in mine rehabilitation it is often not the case as spoils contain large fractions of potentially acidifying material (Bell *et al.*, 2001). The pH in material only gives the current acidity or alkalinity and not the potential acidity or alkalinity. Acidity is a more frequent occurrence in coal-mines of South Africa due to the high pyrite content in the rock formations associated with coal (Bell, 1996). According to Williamson *et al.* (1982) normal plant growth is possible at pH (H_2O) values between 5 and 7. Buys (1986) indicated the optimum pH (KCl) values as between 4.5 and 6. Mengel and Kirby (1987) indicated that the optimal pH (KCl) range for Lucerne is between 6.5 to 7.4, whereas grasses can tolerate pH values as low as 4.1. The maintenance of a vegetation cover is severely restricted at pH (H_2O) values lower than 3 and higher than 9. Good indicators of acidity are base saturation, pH, exchangeable aluminium and total exchangeable acidity (Singer and Munns, 1992). Soil pH as well as potential acidity will determine the solubility of heavy metals and therefore the potential for phyto-toxicity. Since heavy metals concentrations are potentially higher in spoil material in comparison to soil, the potential for heavy metal toxicity will be higher on rehabilitated land. Manganese and aluminium toxicity are especially a problem in acidic growth mediums. Deficiencies of molybdenum, calcium, magnesium and potassium, therefore macro element deficiencies, are frequently experienced under acidic conditions. The reason for macro-element deficiencies is a very low exchangeable base saturation influencing the availability of macro-elements.

Available literature indicates that a pH (H_2O) range of 6.5 to 7 is optimal for plant growth although a pH above 5.5 is tolerable. Havlin *et al.* (1999) illustrated that a pH above 5.6 would eliminate pH-related problems and reduce exchangeable Al^{3+} to less than 10% of the CEC. The guideline in this study is that the topsoil pH (H_2O) must preferably be **between 6.5±0.5** and must **not fall outside a range of 5.5 to 7.5** (Mays & Bengtson, 1978). A too high alkaline pH is also problematic and according to Cumming & Elliot (1991) phosphate adsorption by roots is not possible in soils with a pH above 9. The guideline is set to allow optimum availability of microelements

and phosphate. Below these guidelines, toxicity or nutrient deficiencies and phosphorus adsorption become possible.

Although not explicitly measured during the study, potential acidity must also be considered. Analyses to conduct an acid base accounting are probably advisable when evaluating the acid formation potential of the discard material to be rehabilitated. The Wyoming Department of Environmental Quality (1994) recommend the method as stipulated in Smith *et al.* (1974) to determine the Acid potential (meg $H.100g^{-1}$ or % sulphur) and the USDA method to measure the neutralisation potential of the material in $CaCO_3/1000$ tons material.

1.3.4. Macro elements

The cations calcium, magnesium potassium and sodium together with the anions sulphate, chlorine, carbonate and nitrate are the most important constituents of the soil solution and exchange complex. Calcium, magnesium and potassium are considered critical for plant growth, whereas sodium is detrimental as it can cause dispersion and sodic conditions in the soil. Sodium therefore needs to be preferably as low as possible. In South African soils potassium is frequently deficient for crop production and needs to be supplemented.

Of further importance is the ratio and concentration in which these macro-elements occur in the soil solution and exchangeable matrix since it influences not only the soil physical properties of the soil but also the nutrient status of the soil for effective plant growth. Buys (1986) recommends that the exchangeable macro-element concentration must be Ca 65: Mg 15: K 8: Na 2 in relation to the S-value. The exchangeable macro-element ratio for soil is indicated by Mengell and Kirby (1987) as Ca: 80%: Mg 4-20% K 4%. Havlin *et al.* (1999) indicate exchangeable magnesium lower than 25-50 $mg.kg^{-1}$ as potentially deficient. The ratio of Ca: Mg and K must be considered as important as any imbalance between Ca:Mg or Mg:K may induce deficiencies. A high application of NH_4 may also disrupt the macro-element concentration as it is preferably exchanged to Ca Mg and K by clay minerals.

1.3.5. Soil nitrogen and phosphorus

A common problem with most rehabilitation is the lack of organically available phosphorus and nitrogen (Bradshaw, 1997). Phosphorus and nitrogen are two of the most essential elements needed by plants. The availability of phosphorus and nitrogen is regulated by two different systems in the soil. Nitrogen is mostly dependent on biological processes (decomposition of organic matter, C/N ratio, nitrogen fixation by *Rhizobium* bacteria ext.) whereas phosphorus availability depends on physico-chemical processes (soil mineralogy, pH, calcium content) and also to a lesser extent biological processes such as mycorrhiza activity.

Nitrogen is taken up in large quantities by the plant but is also lost to the plant due to leaching and denitrification. Unfortunately nitrogen is primarily devoid in rehabilitated land (Bradshaw and Chadwick, 1980). Therefore in newly rehabilitated pastures nitrogen must constantly be added through fertilisation or by allowing the ecosystem to assimilate nitrogen by planting legumes inoculated with the correct strain of nitrogen fixing bacteria until sufficient nitrogen is accumulated through biomass, clay particles and biota. In general the role of legumes as nitrogen accumulator has attracted substantial attention (Palmer & Chadwick, 1985) and is generally advocated as the best solution to improve nitrogen budgeting in the soil (Bradshaw, 1997). In South Africa the use of legumes as a natural source of nitrogen during mine rehabilitation has not gained much interest. This is probably because very little indigenous legumes have been cultivated as pasture crop and exotic species have been found to not be well-adapted for local conditions. The occurrence of bloat is also a further reason way legumes are not used during rehabilitation. Bloat is a common condition occurring in ruminant animals. Lucerne, red clover and white clover are among the most notorious legume species causing bloat in temporal regions (Kellerman *et al.*, 1988). Saponins and soluble proteins are primarily responsible for the formation and build-up of foam in the rumen (Kellerman *et al.*, 1988). The importance of legumes as source for nitrogen has been well illustrated. According to Palmer and Chadwick (1985) *Trifolium repens* L was capable of accumulating 376 kg.ha^{-1} nitrogen on colliery spoils. Rethman and Tanner (1995) indicate the beneficial role of alfalfa in a mix pasture in a South African scenario.

Other potential sources of macro-elements are organic matter such as sewage sludge (Bradshaw 1997). Kraal manure from feedlots is frequently used as source of organic matter in South Africa because of its regular availability. Other sources that

are also investigated are for example water treatment sludge (Van Rensburg and Morgenthal (2003) and woodchips from blasted wood buttresses in Platinum mines.

The interaction between NO_3, NH_4 and plant roots is complex and among a variety of factors dependent on pH. Plants can take up both NO_3 and NH_4 forms but studies have shown that NH_4 uptake is higher at neutral pH (pH 6.8) and decreases with acidity. NO_3 uptake is higher at acidic pH conditions (pH 4) (Mengel and Kirby 1987). In general plants take up nitrate more regularly since NH_4, at high concentrations, is phyto-toxic. NO_3, however, requires a higher energy input from the plant to be converted back to NH_4 or amino acids (Mengel and Kirby 1987). The only application of NH_4 as nitrogen source may also be detrimental in soils with a low exchangeable Mg.

Because nitrogen is difficult to accurately determine because of its dynamic nature it is difficult to set guidelines. The post-mining land-use, productivity levels and planted species further determine the required nitrogen in the soil. Williamson *et al.* (1982) indicate that normal soils have a total N in excess of 0.17 ($\equiv$ 0.2%). The Chamber of Mines (1981) proposes an application of 100kg.ha-1 nitrogen under grass-legume pastures. For grass pastures the level of productivity is used to calculate the N-requirement (Chamber of Mines, 1981). Kent (1982) recommends a standard rate of 60 $kg.ha^{-1}$ nitrogen. The EPA (1995) indicates application rates of up to 80 kg.ha-1 nitrogen for the fertilisation of rehabilitated land. Mengel and Kirby (1987) report that concentrations of 2-20 $mg.dm^{-3}$ NO_3 are normal for fertile soils. The South African Water Guidelines also limits the concentration of nitrate to $6mg.dm^{-3}$. A too high nitrate level in the soil solution could also be problematic.

Although phosphorus is one of the most important macro elements for plant growth, it is also the least available to plants. Natural soils in South Africa are frequently phosphorus-poor. The availability of phosphorus to the plant depends on the total phosphorus level in the soil, the mineralogy and soil pH. According to Mengel and Kirby (1987) soil with a high sesquioxides and amorphous aluminium and iron oxides also have a higher phosphorus adsorption capacity especially under low pH-conditions. Phosphate adsorption is greatest in 1:1 layered clay minerals such as Kaolinite, because of the greater amount of oxides and exposed OH-groups in the aluminium layer that can exchange with phosphate. In calcareous soils high in soluble calcium and alkaline conditions, phosphate availability can also be depressed by the precipitation of calcium phosphates. The rule is that soil rich in iron and

aluminium oxides desorption is of greater importance but in poor sandy, calcareous or organic soils phosphate precipitation determines the availability of phosphorus. Phosphorus availability is greatest at a pH range of 6-6.5 (Havlin *et al.*, 1999 and Bergman, 1992).

The Chamber of Mines (1981) used a guideline of 36 g/kg Bray-1 extractable phosphorus. Buys (1986) indicates phosphorus Bray-level of 16-20g.kg sufficient for planted pastures with a low productivity. An annual application of 10kg/ha P is recommended by Buys (1986) to sustain the phosphorus levels above $16g.kg^{-1}$. Mengel and Kirby (1987) indicate a level of $0.01 \ mmol.dm^{-3}$ soluble phosphates as high in terms of soil fertility. A phosphorus level determined from sodium bicarbonate extraction is sufficient between $16-45 \ mg.kg^{-1}$ and becomes excessive at $200mg.kg^{-1}$. Williamson *et al.* (1982) indicate that $20g.kg^{-1}$ phosphorus, extracted with $NaHCO_3$, is sufficient for pastures and extreme deficiencies may occur if the extractable P is below $5mg.kg^{-1}$. This value also agrees with guidelines indicated by Cummings and Elliot (1991). A general guideline for Bray-1 extraction phosphorus is that it must preferably be in the magnitude of $20 \ mg.kg^{-1}$ and must not fall outside the range of $15-200 \ mg.kg^{-1}$. To ensure optimum phosphorus mobility the soil pH must preferably be slightly acidic (pH 6.5). The guideline is set to sustain an acceptable level of productivity.

1.3.6. Micro-element toxicity

Micro-element toxicity is frequently a direct consequence of acid formation as most heavy metals' solubility increase when acidity increases below a pH of 5.5. Of considerable importance is the potential of aluminium toxicity in acidic soils (Mengel and Kirby, 1987). Specific element toxicities will, however, be site specific and will depend on the chemical composition of the coal and cover soil. A well-documented guideline to assess whether element concentrations will affect plant growth is the document by Efroymson *et al.* (1997). More literature is available on plant tissue concentrations as this gives a direct indication of the concentration taken up by the plant itself. The indication of guidelines for micro-element toxicity is, however, problematic due to the variety of methods available for measuring toxicity. It is therefore probably more meaningful to compare results with soils associated with natural or semi-natural grassland sites using the same extraction methods.

2. THE INFLUENCE OF ANNUAL FERTILISATION ON TOPSOIL FERTILITY OF SEVEN REHABILITATED DISCARD DUMPS

2.1. Introduction

Currently colliery spoil heaps are rehabilitated by compacting the discard and covering the discard with cover-soil layer where after the cover soil is seeded with an indigenous grass pasture. Direct rehabilitation on discard is seldom conducted since direct revegetation onto the discard is not seen as feasible and sustainable. Most other major coal mining companies in South Africa probably in principle follow this procedure. Some, especially earlier discard dumps, are shaped following step-designs. To ensure mine closure the responsible company is legally obligated to indicate that the dump does not impact further on the ground water or surface water (South Africa, 1998) and that rehabilitation complies with general sustainability development principles and has not caused any environmental damage, ecological degradation or pollution (South Africa, 2002).

According to Mentis (1999a), ecologically, the primary aim of mine rehabilitation is to establish a grass sward capable of incorporating organic material into the cover soil layer by turnover of root material. Annual fertilisation with regular defoliation is deemed essential to increase root production and turnover, thereby increasing nutrient recycling and soil organic accumulation. Kent (1982) stated that the rate at which essential elements are available during early rehabilitation is critical, since vegetation will only be self-sustainable if nutrient cycling is effective. The establishment of an effective nutrient cycle is difficult to achieve on rehabilitated land. The primary reason for this is the net losses of nutrients due to leaching and runoff (Dennington and Chadwick, 1978). The influence of acidity and low macro-element availability of rehabilitated open-cast land topsoil, on the grass sward was observed by Mentis (1999a) and Rethmann and Tanner (1993). Limpitlaw et al. (1997) found high bulk densities indicating excessive compaction on rehabilitated open-cast land. In South Africa the characteristics of cover soil on open cast areas have been well described by Nell & Steenekamp (1998), through extensive sampling of a variety of open-cast areas. Nell & Steenekamp (1998) reported that unfavourable topsoil texture and bulk densities, due to compaction, are the main physical problems during mine rehabilitation. The result is weakly developed root system which is has a limited distribution. The affecting is poor growth of grasses (Nell & Steenekamp, 1998). Research on the physical limitation of cover soil and spoil materials have

been conducted but have been less useful to reclamation (Vogel & Curtis, 1978) than research in chemical properties. The reason for the lesser attention to physical problems is that it is difficult to correct and can be managed to a limited depth. The tendency is, therefore, to "live with physical problems instead of correct them" (Vogel & Curtis, 1978). In this study soil physical properties were not investigated because the focus was on soil fertility.

In comparison to studies dealing with the initial problems of rehabilitation, the long-term maintenance and aftercare have received little attention (Kent, 1982). Studies have, however, indicated the importance of investigating the rehabilitation process after initial amelioration and seed inputs. Brown and Grant (2000) conducted such a study by comparing the fertility of topsoil and soil rehabilitated land and found that macro-element concentrations was overall higher on spoils. Both areas investigated by Brown and Grant (2000) were deficient in nitrogen. The transformation of nitrogen from total to available nitrate-nitrogen is therefore a problem in open cast spoils material. If no legumes is present for nitrogen fixation follow up fertilisation could be needed (Vogel & Curtis, 1978).

Proper management of nutrient on rehabilitated land is important on rehabilitated land. The objective of the study was to evaluate the cover soil fertility of seven managed rehabilitated discard dumps in comparison to background soil samples and comparable soil fertility guidelines.

2.2.   Materials and methods

2.2.1. Study area

The study was conducted on seven rehabilitated coal discard dumps with rehabilitation ages between 2 and 8 years (Figure 1). The most southern site is situated on the North-eastern border between Kwa-Zulu Natal and the Mpumalanga Province near the town of Newcastle. This dump is also the oldest (rehabilitated during 1998) and biggest (±80ha) of the dumps investigated. The most easterly-situated dumps were situated near the towns of Ermelo and Breyton. Two of the dumps were situated in Witbank. The smallest of the seven dumps were situated to the west of Witbank near the town Ogies.
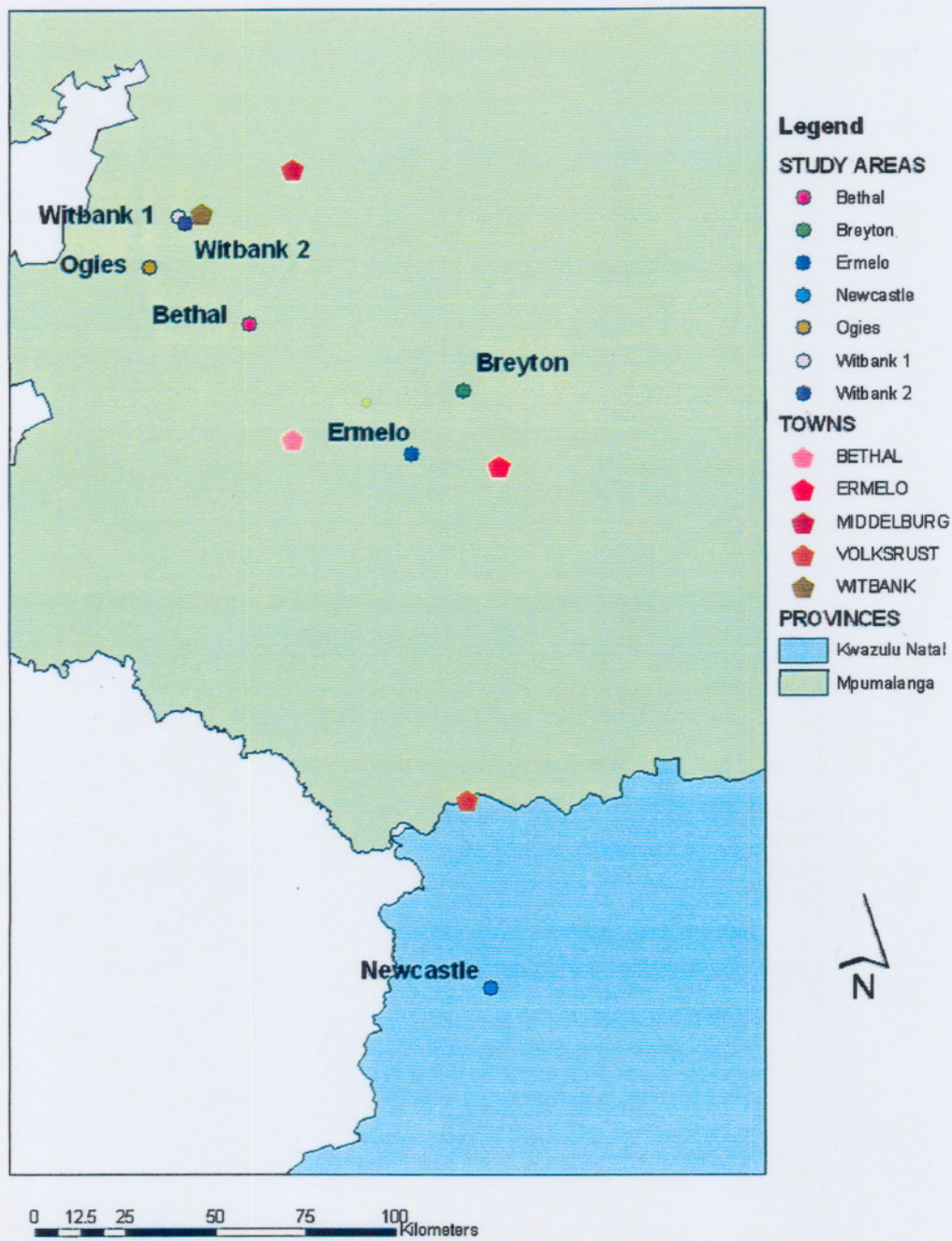
Figure 1. Map of the study area indicating the geographical positions of the seven rehabilitated coal discard dumps used as study areas.

The Newcastle and Ermelo dumps are larger than 60ha in size whereas the Breyton, Ogies and Witbank dumps are smaller dumps between 6-36ha in size. The dumps near Breyton, Ogies, Witbank and Newcastle were covered by topsoil layers less than 300mm, whereas the two younger dumps near Ermelo and Bethal were covered by 500mm of topsoil. The topsoil was from best available soils in the vicinity of the dump. No topsoil was stockpiled but was used as soon as possible. The seven dumps were graded to slope less than 20%. The prescribed slopes on most of the dumps, especially the younger ones are less than 20% slope. On all the larger dumps water management structures in the form of berms and contours were constructed. The Dumps near Breyton and Ogies, due to their small size, followed a whale-back design with no contours. With the exception of one (Newcastle dump) all the larger dumps had a spiral contour system.

All the dumps were rehabilitated with a grass seed mixture mostly consisting of the commercially available grasses *Eragrostis tef* (pioneer crop), *Eragrostis curvula, Chloris gayana, Digitaria eriantha, Cynodon dactylon* and *Pennisetum clandestinum*. Due to the age differences of the dumps, data on initial seed mixtures and fertilisation treatments are not available. Small quantities of veld grasses and pioneers were included on occasion depending on availability. A vegetation assessment conducted in February 2003 indicated that *Digitaria eriantha, Chloris gayana, Cynodon dactylon* and *Eragrostis curvula* were the most frequent species on rehabilitated discard dumps (Morgenthal & Van Rensburg, in press). *Digitaria eriantha* was the most dominant species at Ermelo, *Pennisetum clandestinum* dominated the vegetation at the dump near Breyton and at the Newcastle dump *Paspalum notatum* was the dominant species. The stoloniferous grass *Cynodon dactylon* together with *Eragrostis plana* dominated the vegetation on the dump near Ogies. The dumps in Witbank were mostly dominated by *Chloris gayana* and *Eragrostis curvula*. The annual pioneer *Eragrostis tef* remained an important component of the vegetation at the one-year-old rehabilitated sites (dump near Bethal) but it seems that in the end *Eragrostis curvula* and *Chloris gayana* will dominate the vegetation composition, as these species are the most common perennial grasses. Previous experiences on other rehabilitated areas indicated that *Eragrostis tef* is frequently the dominant species during the first season but is quickly replaced by perennial species and disappears from the grass sward during the third year after seeding.

As a management practice all dumps are defoliated by mowing and / or cattle grazing although grazing is preferred. The grazing strategy being followed is that of short

grazing periods e.g. ten days but at high intensity or cattle loading and long recovery periods. All dumps also received variable amounts of lime, inorganic fertilisers and well-cured kraal manure at the onset of rehabilitation and during annual maintenance. A schedule of fertilisation practices during the past three years from 2000 until 2002 are given in Table 1. Inorganic fertilisers in the form of $CaNO_3$, $MgNO_3$ and KNO_3 were applied (Table 1). These forms of inorganic fertilisers were used to limit acidification of the root zone during uptake of nitrogen by the plant (Van Rensburg per. com.). Organic material in the form of well-cured kraal manure was also applied at 3-10 $Mg.ha^{-1}$ mainly to adsorb excessive salts (Van Rensburg per com.) Calculations showed that at the average total nitrogen content of 0.8% measured for the kraal manure, an application of 5 $Mg.ha^{-1}$ manure would add $40kg.ha^{-1}$ nitrogen to the cover soil, as well as other essential nutrients.

The seven discard dumps are situated within the summer rainfall area and receive an average annual rainfall between 700-800mm (Data provided by the SA Weather Bureau). All the sites are situated within the Grassland Biome. According to the recent vegetation classification by Low and Rebelo (1998) the seven dumps are situated within the Grassland Biome and in particular are distributed over three vegetation types. The dumps near Ogies, Witbank and Bethal in the Mpumalanga Province are situated in the Moist Sandy Highveld Grassland. The surface geology is predominantly shale and sandstone, therefore the sandy soils. Typically natural grasslands are dominated by *Eragrostis curvula, Eragrostis curvula, Heteropogon contortus, Trachypogon contortus* and *Themeda triandra* (Bredenkamp & Van Rooyen, 1998). The Dump near Breyton is situated on the border between the Moist Sandy Highveld Grassland and Moist Clay Highveld Grassland. The dump near Ermelo is situated within the Moist Clay Highveld Grassland (35). Undisturbed Moist Clay Highveld Grassland is exclusively dominated by *Themeda triandra* and is therefore also referred to as *Themeda triandra-Aristida bipartita* Grassland. The soil surrounding the mine is also mostly black Vertisols. Other perennial grasses include among others *Setaria incrassata, Setaria nigrirostris, Heteropogon contortus* and *Brachiaria serrata* (Bredenkamp *et al.*, 1998). The most southern dump near Newcastle is situated in the North Eastern Mountain Grassland vegetation type. The site also borders the Natal Central Bushland (Low & Rebelo, 1998). Typically climax grass sward consists of *Loudetia simplex, Trachypogon spicatus, Aristida junciformis, Tristachya leocothrix* and *Alloteropsis semialata* (Bredenkamp *et al.*, 1998).

2.2.2. Soil sampling

Soil samples were collected annually at specific localities for soil chemical analyses to determine the nutrient requirements of the topsoil in terms of nutrient deficiencies, imbalances and general topsoil quality. A 1:2 water-extraction procedure was followed to determine the water-soluble concentrations of macro-elements and micro-elements, available for uptake by the plant. The soil samples were also analysed for ammonium acetate extractable calcium, magnesium, potassium and sodium during 2000 and 2003. The soil chemical analyses conducted and fertilisers recommended for 200, 2001 and 2002 are given in Table 1.

2.2.3. Soil chemical analysis

All soil chemical analyses were conducted at the soil laboratory of EKO REHAB. The 1:2 (v/v) extraction procedure as described by Rhoads (1982) was used to determine the water-soluble basic cation fraction, (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and trace elements (iron, manganese, copper and zinc). Quantification was done by means of atomic absorption spectrophotometry with a Spectr. AA – 250 (Varian, Australia) (Ramiriz-Munoz, 1968).

The anions, phosphate, nitrate, sulphate and chloride were determined using an Ion Chromatograph (Metrohm 761, Switzerland). Ammonium concentration was determined using an ammonium-selective electrode (Banwart et al., 1972). The bicarbonate content of the media extract was determined by the potentiometric titration method with a pH end-point of 4.5 using a standard 0.005M HCl-solution (Skougstad et al., 1979). Boron concentrations were determined by the azomethine-H method described by Barrett (1978).

Extractable bases were determined using a Spectr. AA-250 (Varian, Australia) following extraction with ammonium acetate solution (Thomas, 1982). Base saturation was calculated by determining the ratio between total extractable cations (Ca, Mg, K and Na) to the cation exchange capacity of the soil as suggested by Buys (1986).

The CEC was determined by a stepwise replacement of the cations from exchange sites by adding sodium acetate, followed by ammonium acetate. The suspension was placed in leach tubes and leached with ammonium acetate to replace the sodium on the exchange complex with ammonium.

Table 1. Fertilisers recommended (kg.ha^{-1}) for the seven rehabilitated discard dumps to maintain topsoil fertility and nutrient balance.

	Ermelo	Witbank 1	Witbank 2	Newcastle	Breyton	Ogies
2000						
$CaNO_3$	100.00	110.00	110.00	90.00	110.00	30.00
$MgNO_3$	30.00	50.00	50.00	50.00	50.00	50.00
KNO_3	85.00	95.00	95.00	80.00	70.00	80.00
Super Phosphate	200.00	200.00	200.00	0.00	150.00	150.00
Manure	5000.00	10000.00	5000.00	10000.00	3000.00	7000.00
Calcitic lime	0.00	100.00	0.00	200.00	0.00	75.00
Inorganic N	30.35	36.35	36.35	31.53	32.89	23.30
Organic N	40.00	80.00	40.00	80.00	24.00	56.00
2001						
$CaNO_3$	240.00	0.00	0.00	0.00	180.00	220.00
$MgNO_3$	100.00	100.00	100.00	0.00	0.00	120.00
KNO_3	260.00	120.00	120.00	0.00	0.00	100.00
Super Phosphate	0.00	0.00	0.00	0.00	0.00	250.00
Manure	0.00	0.00	0.00	0.00	0.00	10000.00
Calcitic lime	0.00	0.00	0.00	11000.00	0.00	0.00
3:1:5 (38)	0.00	0.00	0.00	280.00	0.00	0.00
Inorganic N	85.14	32.84	32.84	35.47	24.69	63.49
Organic N	0.00	0.00	0.00	0.00	0.00	80
2002						
$CaNO_3$	90.00	100.00	100.00	0.00	120.00	80.00
$MgNO_3$	25.00	35.00	35.00	0.00	50.00	35.00
KNO_3	80.00	50.00	50.00	120.00	0.00	45.00
Super Phosphate	120.00	150.00	150.00	250.00	0.00	100.00
Manure	0.00	0.00	5000.00	0.00	0.00	3000.00
Dolomitic lime	5000.00	0.00	5000.00	0.00	0.00	0.00
Inorganic N	27.48	26.32	26.32	16.62	24.57	22.88
Organic N	0.00	0.00	38.80	0.00	0.00	24

The sodium concentration of the leachate, determined with a Spectr. AA-250 (Varian, Australia) was then used to calculate the cation exchange capacity (CEC).

The pH (water) and pH (KCl) were determined by adding 50 ml deionised water or KCl to 20 g media. The suspension pH was measured with a calibrated pH/conductivity meter (Radiometer pHM 80, Copenhagen). The supernatant for determining the electrical conductivity was prepared by adding 50 ml of deionised water to 50 g of medium. The electrical conductivity of the supernatant was measured with a WTW LF92 conductivity meter. Available phosphate was determined by adding 75ml Bray-1 solution to 10 g medium. The phosphate concentration was analysed with a Continuous Flow Analysis System (Skalar, Netherlands), at 340 to 650 nm in a 15 mm tubular flow cell.

The organic carbon content was determined with the Walkley-Black method (Walkley, 1935).

Exchangeable acidity is quantified by applying KCl to the filtrate and titrating the product with NaOH (Rhoads, 1982).

The percentage sand, silt and clay were analysed by separating the sand fraction from the percentage silt and clay, where-after the clay percentage was quantified with the hydrometer (Gee & Bauder, 1986).

Clay mineralogy was determined at the soil laboratory of the Institute for Soil Climate and Water following the method described by Alexiades and Jackson (1966) and Whittig and Allardice (1986).

2.2.4. Data analysis

Data were analysed with STATISTICA for Windows (Statsoft, 2003) and CANOCO ver 4 (Ter Braak & Šmilauer, 1998). To improve the normality, soil chemical data were log transformed. Normality was evaluated by plotting the expected normal value against the data. A repeated measure ANOVA was conducted with the dumps (Ermelo, Newcastle, Breyton, Ogies and Witbank) as factor and the year of survey (2000, 2001 and 2002) as repeated measure. The dumps were included in the analysis to account for the variance between the different sites.

The topsoil quality was assessed by comparing the cover soil samples with twelve background samples obtained from semi-natural grasslands soils collected in the vicinity of the dump with the non-parametric Mann Whitney U Test. Based on the South African soil classification (Soil Classification Work Group, 1991) one sample was from a Shortlands soil (Newcastle), six samples were from soils of the Clovely form (Newcastle, Ermelo and Witbank), two samples were Glenrosa soils (Newcastle) and three samples were Arcadia soils (Ermelo).

A Principle Component Analysis was conducted to ascertain the chemical variables that explain the variance among samples most successfully. The first PCA axis is the direction that captures the most variance and the remaining sequence of axes will explain, in diminishing importance, the remainder of the variance (Gauch, 1982).

A partial Redundancy analysis, which is a linear ordination method, was thereafter conducted to relate the input of fertilisers to changes in soil chemical properties during a three-year period. By simultaneously including many independent and dependent variables, it becomes possible to detect the main tendencies and patterns between dependent variables and between dependent variables and independent variables (Jongman *et al.*, 1995). Because the differences among dumps were accounted for by including them as co-variable the ordination is referred to as a partial RDA analysis. The dumps were included as co-variables to exclude unnecessary noise contributed to the differences among dumps. The results are portrayed in a biplot with the soil chemical variables (dependent variables) and applied fertilisers (independent variables) as vectors. The cosine of the angle between the independent variables and dependent variables is an approximation of the correlation coefficient between them (Jongman *et al.*, 1995). Fertiliser applications from 2000 and 2001 were compared with soil chemical data from 2001 and 2002. Because previous fertiliser treatments are not known the assumption of no fertiliser applications were made for the 2000 soil chemical data.

2.3.   Results and discussion

2.3.1. Soil physical properties

The soil physical characteristics (topsoil depth, dominant soil colour (Munsell, 2000) texture class, structure) are summarised in Table 2. The topsoil on the Ermelo dump can be described as a dark reddish brown soil with a clay loam texture (clay% 35%

clay and 23.8% silt). X-ray diffraction indicates kaolinite (53%) to be the dominant clay mineral. Quarts made up a large fraction of the soil mineralogy. Small quantities of smectite, mica, goethite and feldspar were also measured. The topsoil thickness varied between 300 and 770 mm, the median topsoil depth being 590 mm. The topsoil predominantly had a massive structure and therefore was not well developed. Since it was difficult to auger at certain depths, compaction could be a potential problem.

The cover soil on the Newcastle dump was a clay loam (28% clay and 29% silt), dark greyish brown to very dark brown coloured soil. The topsoil was orange, yellow and black mottled. On average 50% of the clay was characterised as kaolinite. One of the two samples containing smectite clays. The occurrence of smectite clay is significant since it has a high cation exchange capacity but has a high shrink and swell potential. Due to the high exchange capacity it is also well-buffered. The topsoil was shallow and was on average 220 mm thick, varying as low as 90 mm to 460 mm (Table 2). The topsoil was characterised by a strong consistency that can be described as sticky or plastic in most of the samples taken.

The topsoil on the two Witbank dumps can be described as a light olive brown to dark yellowish brown topsoil with a loam sand texture (6.33% clay and 12.6% silt). Sixty nine percent of the clay was kaolinite (Table 2). Some of the samples contained small quantities of mica and goethite. The topsoil depth varied between 150-480 mm with a median of 245 mm. The topsoil depth of the first dump was slightly deeper than the second dump. The structure of the topsoil is apedal with a loose consistency.

The small dump at Ogies was covered by an average topsoil thickness of 166 mm (140-220 mm) with a very dark grey soil colour and sand soil texture.

Table 2: Soil physical properties measured for the cover soil, at the seven rehabilitated discard dumps. Values in italics indicate standard deviation from the mean

	Particle size distribution			Clay mineralogy								Soil depth	Colour		Colour	Consistency
Dump	Clay	Sand	Silt	Kaolinite	Quartz	Mica	Goethite	Smectite	Inter-stratified	Feldspar	Calcite		Munsell			
							%					mm				
Bethal	6.6	64.4	29.1	66.0	22.00	7.43	4.00	0.00	0.57	0.00	0.00	522.14	2.5YR	4/6 or 3/6	Red to dark red	slightly hard
	1.5	*1.6*	*1.3*	*7.2*	*7.09*	*3.51*	*3.21*	*0.00*	*1.51*	*0.00*	*0.00*	*57.54*				
Ermelo	35.3	40.9	23.8	53.7	32.67	3.67	1.50	3.17	3.50	1.83	0.00	536.82	5YR	3/4	Dark Reddish Brown	hard
	6.2	*6.8*	*2.7*	*9.3*	*6.47*	*5.72*	*3.67*	*4.92*	*5.43*	*4.49*	*0.00*	*163.04*				
Breyton	10.0	74.3	15.7	16.0	73.00	0.00	1.50	0.00	0.00	6.00	3.50	268.00	10YR	3/1	Very Dark Grey	loose
	2.3	*2.2*	*1.4*	*9.9*	*5.35*	*0.00*	*3.00*	*0.00*	*0.00*	*8.49*	*7.00*	*54.32*				
Newcastle	28.0	42.7	29.3	50.2	29.33	6.00	2.50	6.33	5.00	0.67	0.00	240.56	10YR	4/2	Dark Greyish Brown	very hard
	7.0	*8.1*	*6.1*	*11.5*	*10.61*	*5.18*	*4.18*	*11.34*	*5.73*	*1.63*	*0.00*	*85.99*				
Ogies	7.5	84.3	8.2	29.0	66.25	1.50	0.00	0.00	0.00	3.25	0.00	166.00	10YR	3/1	Very Dark Grey	loose
	1.0	*3.9*	*3.3*	*18.8*	*17.35*	*3.00*	*0.00*	*0.00*	*0.00*	*6.50*	*0.00*	*30.62*				
Witbank 1	8.7	80.9	10.5	68.0	21.00	1.33	7.00	0.00	2.67	0.00	0.00	325.00	10YR	4/6	Dark Yellowish Brown	loose
	4.2	*2.9*	*6.5*	*8.7*	*4.58*	*2.31*	*1.00*	*0.00*	*4.62*	*0.00*	*0.00*	*102.96*				
Witbank 2	4.0	81.3	14.7	71.7	18.67	5.67	4.00	0.00	0.00	0.00	0.00	223.33	10YR	5/6	Yellowish Brown	loose
	0.0	*1.8*	*1.8*	*4.0*	*6.03*	*1.15*	*3.46*	*0.00*	*0.00*	*0.00*	*0.00*	*57.88*				

The clay mineralogy consists dominantly of kaolinite and quartz. The structure of the topsoil is apedal with a loose consistency.

The three small dumps near Breyton are covered on average with 268mm (150-310mm) reddish to dark grey topsoil with a loamy sand texture.

The newly rehabilitated dump near Bethal is covered with dark red, red to yellowish red topsoil with a sandy loam texture. Topsoil thickness measurements varied between 450 to 600mm and were on average 500mm. The mineralogical composition is 66% kaolinite, 22% quartz, 7% mica and 4% goethite. The cover soil had a massive apedal structure. Auguring was difficult at certain depths therefore compaction and surface crust formation were present.

2.3.2. Soil chemical properties

Table 3 lists the background values (mean, standard deviation and median value) measured in 12 soil samples collected in grassland sites in the vicinity of the rehabilitated discard dump.

The soil fertilisation data were based on 1:2 (v/v) water extraction analyses and ammonium acetate analyses. Data from three years of sampling were therefore available for analysis. The change in soil fertility will be discussed for the five dumps, Ogies, Witbank, Ermelo, Breyton and Newcastle, over a three-year survey period (Tables 4, 5 and 6).

The ammonium acetate analysis was conducted to determine the extractable cations calcium, magnesium, potassium and sodium. The extractable cations indicate the available soluble and exchangeable macro-elements in the soil. The exchangeable macro-elements are those macro-elements bound to the negative charges clay minerals created during isomorphic replacement of trivalent with divalent cations on the layered silicates. The exchangeable concentrations expressed as $cmol_c.kg^{-1}$ were used to calculate the base saturation and the ratio between calcium, magnesium, potassium and sodium.

The extractable calcium on all dumps was on average above 1000 $mg.kg^{-1}$ with the exception of the dumps near Witbank that had on average a low extractable calcium of 188-542 $mg.kg^{-1}$ (Table 4). The lower and upper quartiles, which is an indication of the non-outlier range varied between 874-2081g/kg^{-1}.

Table 3. Performance indicator nutrient values to assess the topsoil quality on rehabilitated dumps. The mean and median values are from 12 natural soil samples collected in the vicinity of the dumps surveyed.

		Mean	Std. Dev.	Median
Ca		4.92	7.97	2.66
Mg		5.45	4.34	4.01
K		11.21	8.06	8.99
Na		1.78	2.49	0.92
SO_4		16.75	8.15	15.31
NO_3		10.90	13.30	6.93
NH_4	$mg.dm^{-3}$	0.81	0.30	0.86
Cl		9.31	6.40	6.83
HCO_3		19.77	27.94	13.73
Fe		1.54	0.80	1.43
Mn		0.15	0.07	0.16
Cu		0.05	0.04	0.05
Zn		0.08	0.06	0.07
B		0.32	0.17	0.37
Ca		1280.21	1305.77	716.25
Mg		486.92	562.42	263.75
K	$mg.kg^{-1}$	259.00	176.92	193.50
Na		9.92	6.23	9.50
P		9.25	5.83	6.68
$pH(H_2O)$		6.03	0.74	5.93
pH(KCl)		5.03	0.77	4.84
EC	$mS.m^{-1}$	25.50	12.89	22.50
CEC	$cmol_c.kg^{-1}$	14.86	11.73	9.80
S-value		11.10	11.39	6.39
Base saturation	%	64.07	20.40	65.09
%C		2.42	1.47	1.92

The low extractable calcium is expected at the Witbank dumps since it had a sandy texture and the cation-exchangeable capacity (CEC) of the soils on these two dumps varied between 2.9 $cmol_c.kg^{-1}$ and 8.4 $cmol_c.kg^{-1}$ and was on average 5 $cmol_c.kg^{-1}$ (Table 4). The continuous addition of lime and $CaNO_3$ increased the extractable calcium on the six dumps surveyed during 2000 to 2002 from 200 to 780 $mg.kg^{-1}$ calcium. The highest extractable calcium was recorded on the Breyton dump (4146

mg.kg^{-1}). The lowest extractable calcium (70 mg/kg^{-1}) was recorded on the Witbank dumps resulting in a low base saturation of 12.4% (Table 4).

The average extractable magnesium on the six dumps surveyed during the three years was 499 mg.kg^{-1}. The non-outlier range (lower and upper quartiles) was 136.5 and 762.5 mg.kg^{-1}. On the dumps covered by high clay content soil the extractable magnesium was on average 625 mg.kg^{-1} and on the dumps covered by a sandier medium 213 g.kg^{-1}. The average extractable magnesium on the dumps also increased during 2000 and 2002 between 62 to 287 mg.kg^{-1} magnesium per dump.

Statistically the extractable potassium values were highly skewed to the left and were therefore not normally distributed. The median concentration for the six dumps was 148.5 g.kg^{-1}. The non-outlier range for extractable potassium on the seven dumps was 102.5 to 230.5 g.kg-1 although the minimum value measured was 5 g.kg^{-1} (Witbank dumps) and the highest 1428 g.kg^{-1} (Breyton Dump) (Table 4). The extractable potassium followed the same tendency as the extractable calcium and magnesium and increased during the 2000-2002 period (Table 4). The increase in extractable potassium was particularly high (>200 g.kg^{-1} increase) at Ermelo, Breyton and Ogies dumps. The increase in extractable potassium was in the magnitude of 95 g.kg^{-1} at Witbank and Newcastle. From a soil fertility perspective the average potassium on the Newcastle, Ogies and Witbank dumps was slightly lower than the norm of 120 g.kg^{-1} but increased on all dumps above the norm value. The extractable potassium on the Breyton dump is already in excess.

The extractable sodium content was also highly skewed to the left. On all the dumps the extractable sodium constituted only a small percentage (0.54%) of the exchange complex. High extractable sodium values were measured on the Newcastle dumps (median 39.5; 22.5-65.0 g.kg^{-1}) and Ermelo dump (median 25.0; 17.5-34.5 g.kg^{-1}) but the sodium constituted only 0.2 to 7.8% of the exchange complex on these dumps.

The ratio between the four macro-elements calcium, magnesium, potassium and sodium are considered important as imbalances could affect vegetation growth and impact on the soil physical properties of the growth medium. The exchange complex of fertile soil should be saturated with 65-85% calcium, 6-12% magnesium and 3-5% potassium. Buys (1986) reports similar values (Ca: 65%; Mg: 25%; K: 8%) but further indicates that the extractable sodium content must be in the magnitude of 2%. In light of this the dumps had a comparably similar percentage exchangeable Ca

(average 64.21% Ca) although the dump at Ogies had a particularly high >70% exchangeable calcium. The exchangeable magnesium (average 29.1%) was also on average comparable to the indicated guideline value of 25%. The highest percentage exchangeable magnesium was reported at Ermelo (Table 4). The average percentage exchangeable potassium was 5.3%. In comparison with the other macro-elements sodium constituted less than 2% of the total exchangeable cations. Table 4 indicates the average cation exchange capacity measured for the three years at the six dumps. The dumps near Ermelo and Newcastle had average CEC values of 18.66 ±3.77 $cmol_c.kg^{-1}$ and 18.26 ±6.35 $cmol_c.kg^{-1}$, which is typical of loam soils (Buys 1986). Kaolinite clays dominated the clay mineralogy of cover soil on the dumps near Ermelo (53.67 ± 9.33%) and Newcastle (50.17 ± 11.53%) (Table 2). Two samples from the topsoil of Ermelo and Newcastle contained respectively 9 and 10%, and 10 and 28% smectite (Table 2). The average CEC at Ogies, Witbank and Breyton were respectively 9.43 ±4.44 $cmol_c.kg^{-1}$, 5.05 ±1.40 $cmol_c.kg^{-1}$ and 12.40 ±6.97 $cmol_c.kg^{-1}$. The topsoil CEC at Ogies, Witbank and Breyton were typical of sandy soils (Buys 1986). Quartz was the dominant clay mineral on these dumps and Kaolinite made up, on average for the respective dumps, 16.00 ± 9.90%, 29.00 ±18.78% and 69.83 ±6.37. Considering that the reported CEC for the dominant clay mineral, Kaolinite is 5-15 (Buys 1986 and Mengel and Kirby, 1987), 5-10 $cmol_c.kg^{-1}$ (van der Watt & van Rooyen, 1990) and 1-10 $cmol_c.kg^{-1}$ (Havlin et al., 1999) the CEC in the topsoil must further be influenced by other factors. A possibility for the higher than expected CEC values in the cover soils and the increase in CEC during the three years at some dumps can be attributed to the addition of large qualities of kraal manure to the surface. Organic material can add 100-400 $cmol_c.kg^{-1}$ cation exchange capacity to the soil (Buys, 1986). A further important influence of CEC is the pH which influences the charge on the clay minerals. The exchange capacity of kaolinite (1:1 layered minerals) and oxides for example Ferrihydrite, Goethite and Gibbsite, is specifically sensitive to changes in soil pH (Dinauer, 1977 and Mott, 1988). The remainder of the soil mineralogy constituted of non-clay minerals such as Mica, Goethite, Feldspar and Calcite. Smectite (CEC: 80-100 $cmol_c.kg^{-1}$) is the only other clay mineral found infrequently in topsoil samples of the Ermelo and Newcastle dumps that could have contributed to the cation exchange capacity. A possible explanation for the higher than expected CEC, on the Ogies and Breyton dumps, is the high organic carbon percentage of 2.44 ±0.90% and 3.35 ±2.30% measured on these dumps. According to values provided by literature organic material can have a cation exchange capacity of 100-300 $cmol_c.kg^{-1}$ (Havlin et al., 1999). Williamson et

al. (1982) reported that the CEC of fine uranium tailings increased from 1 to 3.43 $cmol_c.kg^{-1}$ with the increased application of organic matter from 5 to 78 $ton.ha^{-1}$ sewage sludge. The increased application of sewage sludge resulting in a noticeable decrease in extractable heavy metals such as iron and aluminium in the uranium tailings (Williamson et al., 1982).

The availability of nitrogen and phosphorus for effective plant growth is regarded as critical. McGinnies & Crofts (1986) could not find improvement of seedling establishment from applying nitrogen before revegetation but both the amount and placement of nitrogen effected production in the third season. Studies have attributed higher plant production to increase applications of nitrogen (Rethman and Tanner, 1995, Rethman, 1987). McGinnies and Groft (1986) also concluded that phosphorus application is beneficial for alfalfa since it increases the production of alfalfa. The available Bray-1 extractable phosphorus and soluble nitrogen in the form of nitrate and ammonium are summarised in Table 5. The average levels of soluble nitrate were in all six dumps higher than the soluble ammonium concentrations. With the exception of Witbank the nitrate level were sufficient for normal plant growth and with the exception of the dump at Newcastle remained fairly constant or increased over the three-year period.

With the exception of the Witbank dumps (the ammonium concentration decreased from 6 $mg.dm^{-3}$ to 2.2 $mg.dm^{-3}$), the average ammonium concentration in the soil solution remained constant and did not show an increase in nitrate due to the continual input of nitrate fertilisers. This can be attributed to the easy assimilation of nitrate by roots and micro-organism. Nitrogen as nitrate is also easily leached from the soil profile meaning that a considerable portion of nitrogen is annually lost. The nitrate concentration was higher than the ammonium concentrations in the soil solution (Table 5).

The average Bray-1 extractable phosphorus in the topsoil of the Ermelo, Newcastle and Witbank dumps were below the guideline of 40 $mg.kg^{-1}$. With the exception of the 2000 and 2001 samples taken at Ermelo, the six dumps had higher Bray-1 phosphorus concentrations than that measured for grassland soils (grassland soil phosphorus was 9.25 $mg.kg^{-1}$) (Table 5). The extractable phosphorus on Ermelo increased from 7.9 to 17 $mg.kg^{-1}$, the extractable phosphorus in the topsoil of the Newcastle dump remained constant at 10-13 $mg.kg^{-1}$ and the extractable phosphorus in the sandy topsoil of the Witbank Dumps increased from 12.7 to 32.7 $mg.kg^{-1}$.

Table 4. Results of the ammonium acetate analyses (measured in mg.kg⁻¹) for 2000, 2001 and 2002 on seven rehabilitated discard dumps. Values in italics indicate standard deviation from the mean.

Mine		Ermelo			Breyton			Newcastle			Ogies			Witbank		
Year		2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002
Ca	†††	1746.50	1758.55	1954.23	1059.25	2168.75	1841.83	1284.82	1482.45	1867.16	1401.75	961.00	1806.00	188.60	247.20	541.92
	‡	*381.50*	*798.23*	*601.31*	*1159.51*	*1319.05*	*812.77*	*575.30*	*901.09*	*739.40*	*1084.35*	*822.37*	*1106.51*	*171.50*	*78.52*	*307.83*
Mg	†††	780.41	740.45	842.62	253.00	723.75	540.08	335.59	534.00	555.63	136.25	88.00	256.50	26.70	31.70	73.83
		196.86	*228.72*	*230.83*	*258.59*	*772.37*	*303.90*	*225.79*	*396.48*	*190.01*	*94.40*	*33.94*	*124.49*	*13.02*	*18.58*	*33.59*
K	†††	133.64	144.59	392.46	360.38	557.25	639.08	82.00	127.86	177.09	89.25	142.75	293.25	47.60	128.20	137.08
		39.14	*46.30*	*176.65*	*469.82*	*584.76*	*389.24*	*34.45*	*40.03*	*61.52*	*83.79*	*60.46*	*133.84*	*37.30*	*44.19*	*74.42*
Na	†††	19.45	48.86	31.81	3.75	71.13	14.25	20.36	102.73	40.47	3.00	39.25	14.38	0.00	61.90	9.67
	‡‡‡	*6.06*	*6.16*	*27.92*	*4.29*	*28.54*	*7.61*	*18.47*	*66.92*	*16.57*	*4.24*	*20.15*	*10.74*	*0.00*	*9.46*	*3.75*
Ca%		56.46	56.27	54.68	65.75	64.65	63.04	71.16	64.44	65.96	84.88	77.45	75.48	76.40	66.46	72.38
Mg%		*40.98*	*39.85*	*38.77*	*26.56*	*28.14*	*27.98*	*24.98*	*27.33*	*29.65*	*13.38*	*13.54*	*18.98*	*20.00*	*9.74*	*17.38*
K%		2.24	2.50	5.98	7.67	5.72	8.63	3.52	5.10	3.42	1.74	5.37	5.17	3.61	11.97	9.05
Na%		*0.32*	*1.38*	*0.57*	*0.03*	*1.49*	*0.34*	*0.34*	*3.13*	*0.97*	*0.00*	*3.64*	*0.37*	*0.00*	*11.83*	*1.19*
CEC		19.23	18.60	18.23	9.19	14.52	13.12	16.66	17.90	19.58	7.61	7.37	11.37	4.79	5.91	4.54
		4.80	*4.04*	*2.66*	*8.29*	*9.20*	*4.66*	*8.61*	*6.85*	*3.86*	*5.94*	*2.57*	*4.70*	*0.82*	*1.72*	*1.35*
Base	†††	80.98	81.09	94.76	78.81	116.44	107.85	50.16	51.59	70.31	102.92	71.71	96.24	17.43	30.29	76.00
saturation (%)	‡‡	*15.12*	*20.57*	*23.06*	*22.99*	*14.90*	*21.59*	*32.90*	*20.39*	*35.99*	*1.56*	*34.65*	*22.31*	*11.33*	*10.87*	*29.33*

Year factor: significance at $p \leq 0.05^{†}$; $0.01^{††}$, $0.001^{†††}$

Combined Year-dump factor: significance at $p \leq 0.05^{‡}$; $0.01^{‡‡}$, $0.001^{‡‡‡}$

Table 5. Available phosphate, soluble nitrogen and micro-elements in topsoil of seven rehabilitated discard dumps determined from the 1:2 water extraction procedure. Values in italics indicate standard deviation from the mean.

		Ermelo			Breyton			Newcastle			Ogies			Witbank		
		2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002
NO_3		20.06	6.81	20.56	27.12	24.45	42.97	25.64	20.84	4.07	3.10	6.24	16.88	0.99	3.10	4.65
		20.40	*9.99*	*24.58*	*22.68*	*23.52*	*37.02*	*52.10*	*48.99*	*5.15*	*1.75*	*3.52*	*13.71*	*1.29*	*1.26*	*5.96*
NH_4 [†††]	mg.dm⁻³	3.00	2.19	3.67	5.08	4.44	4.15	3.11	2.30	2.56	2.80	0.11	2.95	5.96	1.16	2.20
		1.67	*0.72*	*6.29*	*0.64*	*2.45*	*1.65*	*2.16*	*2.63*	*3.41*	*0.00*	*0.00*	*2.15*	*1.21*	*0.56*	*0.71*
$N\ (NO_3+NH_4)$		1.61	0.77	1.76	2.37	2.11	3.00	1.91	1.51	0.70	0.70	0.34	1.44	1.21	0.38	0.67
		1.27	*0.50*	*2.37*	*1.12*	*1.29*	*2.16*	*2.66*	*2.92*	*0.88*	*0.09*	*0.18*	*1.06*	*0.24*	*0.12*	*0.37*
P (Bray-1) †	mg.kg⁻¹	7.94	5.84	17.00	61.63	259.94	238.33	9.58	13.30	12.94	64.33	44.31	111.94	12.72	13.29	32.74
		2.48	*1.79*	*37.24*	*93.04*	*285.27*	*128.48*	*4.97*	*13.91*	*8.45*	*61.59*	*17.86*	*38.96*	*8.09*	*5.14*	*20.88*
SO_4		50.48	105.18	59.54	19.45	34.12	37.51	498.73	692.37	422.46	111.91	23.14	40.40	77.62	75.57	34.44
		19.73	*173.71*	*40.41*	*20.59*	*33.20*	*23.30*	*583.64*	*702.70*	*519.63*	*74.04*	*5.98*	*30.36*	*47.44*	*28.58*	*19.61*
Cl		7.77	5.42	36.34	6.03	12.62	18.12	8.06	6.26	4.07	3.19	5.09	4.07	3.97	3.75	3.79
		6.34	*3.24*	*55.86*	*4.26*	*11.78*	*16.94*	*12.35*	*10.31*	*3.22*	*1.00*	*4.75*	*1.94*	*3.22*	*1.18*	*2.50*
Fe †	mg.dm⁻³	0.24	0.13	0.11	9.26	3.44	7.42	1.00	0.38	0.48	2.71	3.77	2.49	0.08	1.01	11.85
		0.21	*0.07*	*0.13*	*4.47*	*1.16*	*4.25*	*1.67*	*0.25*	*0.83*	*2.30*	*0.04*	*1.77*	*0.17*	*1.53*	*5.39*
Mn †		0.02	0.02	0.02	0.21	0.09	0.05	4.44	6.49	2.34	0.05	0.03	0.05	0.17	0.09	0.06
		0.01	*0.04*	*0.02*	*0.20*	*0.03*	*0.03*	*8.72*	*11.65*	*4.99*	*0.02*	*0.03*	*0.03*	*0.19*	*0.05*	*0.04*
Cu		0.01	0.01	0.00	0.07	0.04	0.04	0.05	0.02	0.01	0.02	0.02	0.01	0.03	0.02	0.02
		0.01	*0.01*	*0.01*	*0.03*	*0.03*	*0.02*	*0.05*	*0.02*	*0.01*	*0.00*	*0.02*	*0.01*	*0.03*	*0.00*	*0.02*
Zn		0.01	0.02	0.01	0.06	0.04	0.03	0.12	0.18	0.04	0.06	0.02	0.02	0.01	0.02	0.02
		0.02	*0.02*	*0.01*	*0.07*	*0.03*	*0.01*	*0.18*	*0.29*	*0.07*	*0.01*	*0.00*	*0.00*	*0.01*	*0.01*	*0.02*

Year factor: significance at $p \le 0.05$ [†]; 0.01 [††], 0.001 [†††] **Combined Year-dump factor**: significance at $p \le 0.05$ [‡]; 0.01 [‡‡], 0.001 [‡‡‡]

Table 6. The ratio and significance between the cover soil chemical property characteristics and background samples

		Breyton		Ogies		Witbank		Newcastle		Bethal		Ermelo	
1:2 water extractable	Ca	2.10	*	3.46	***	0.38	Ns	22.96	***	5.68	***	4.19	***
	Mg	1.24	Ns	0.63	Ns	1.65	Ns	9.55	***	1.66	Ns	2.25	*
	K	4.39	**	2.30	Ns	0.69	Ns	0.62	Ns	1.05	Ns	0.46	***
	Na	2.04	Ns	1.89	*	0.48	Ns	9.86	***	1.70	Ns	2.30	***
	SO₄	1.87	Ns	3.22	*	0.28	***	30.43	***	6.44	***	4.24	***
	NO₃	3.04	Ns	0.99	Ns	3.60	Ns	1.36	Ns	0.73	Ns	1.48	Ns
	NH₄	1.79	**	0.88	Ns	0.82	Ns	1.05	Ns	0.49	**	1.19	Ns
	Cl	1.39	Ns	0.44	Ns	2.46	*	0.61	**	1.26	Ns	1.87	Ns
	HCO₃	3.36	**	2.12	Ns	1.77	Ns	0.57	*	2.21	*	62.80	Ns
	Fe	4.42	***	1.86	Ns	0.32	*	0.47	***	0.05	***	0.10	***
	Mn	0.73	*	0.31	Ns	1.39	*	27.55	*	0.09	***	0.13	***
	Cu	1.05	Ns	0.34	*	2.24	Ns	0.49	*	0.16	*	0.19	***
	Zn	0.51	*	0.42	*	4.37	***	1.29	Ns	0.08	**	0.15	***
	B	1.23	Ns	0.41	**	3.67	**	0.30	***	0.12	**	0.06	***
Ammonium acetate	Ca	1.34	Ns	1.17	Ns	3.77	*	1.25	*	0.97	Ns	1.43	**
	Mg	1.05	Ns	0.38	Ns	10.60	***	0.98	Ns	0.47	Ns	1.62	**
	K	2.07	Ns	0.79	Ns	2.44	**	0.51	Ns	0.62	Ns	0.90	Ns
	Na	2.77	Ns	1.79	Ns	0.43	Ns	5.21	***	1.26	Ns	3.36	***
	P	20.97	***	8.99	***	0.45	Ns	1.29	Ns	1.68	Ns	1.15	Ns
	pH(H₂O)	1.20	***	1.14	*	0.96	Ns	0.95	Ns	1.28	***	1.12	**
	EC	1.82	*	2.03	*	0.79	*	5.63	**	1.82	**	1.44	Ns
	CEC	0.83	Ns	0.63	Ns	2.94	**	1.21	Ns	0.48	Ns	1.26	**
	%C	1.01	ns	1.38	Ns	4.86	***	0.65	Ns	0.12	***	0.20	***

Significance at p≤ 0.05*, 0.01**, 0.001*** as determined by the Mann-Whitney U test between natural soil and cover soil

The extractable phosphorus in the soils of the Breyton and Ogies dumps was above 40 mg.kg^{-1} (Table 5). The extractable phosphorus on the Breyton Dump increased from 61.6 mg.kg^{-1} to in excess of 200 mg.kg^{-1} although it received only 150 kg.ha^{-1} super phosphates in 2000. The difference in extractable phosphorus between the dumps, although all dumps received 200kg.ha^{-1} super phosphate, highlights the effect of phosphorus adsorption in soils and the dynamics between labile and non-labile phosphate (Mengel & Kirby, 1986). Extractable phosphorus increased considerably on the Ogies dump from 64 mg.kg^{-1} to 112 mg.kg^{-1} after applications of 250 and 150 kg.ha^{-1} super phosphate during 2000 and 2001. The extractable phosphate also responded well with the application of 200 kg.ha^{-1} super phosphate. According to Havlin et al. (1999) phosphorus adsorption is higher in soils containing 1:1 clay minerals since these have higher amounts of Fe/Al oxides associated with such clays than with 1:2 clay minerals. The need for higher applications of phosphate fertilisers on the seven dumps can possibly contribute to the high concentration of kaolinite clays, which forms the predominant clay mineral on all seven dumps. Considering this, the dumps at Ermelo and Newcastle will particularly require high applications of phosphorus fertilisers. The management of soil acidity on these dumps will be more critical than at Witbank and Ogies dumps. These dumps must, however, not be over-limed as this could result in the precipitation of phosphorus as P-Ca minerals (Mengel and Kirby 1986).

Table 5 summarises the average micro-element concentrations in the soil solution determined with a 1:2 water extraction procedure. The chlorine concentration in the soil solution for all dumps was on average 10.07 mg.dm^{-3} and was similar to concentrations measured in grassland soils (Table 3 and 5). Most chlorine values ranged from 2.8 to 7.4 (25-75% quartiles) but outlier values of 30-45 mg.dm^{-3} up to 173 mg.dm^{-3} chlorine were measured in the topsoil of the Ermelo, Breyton and Newcastle dumps. On average the chlorine values remained relatively constant on the different dumps with the exception of the Ermelo dump where an increase in chlorine concentrations were experienced from 2001 to 2002 (Table 5). This corresponds to the initiation of grazing on the dump.

On average the soluble iron concentration in the topsoil of the seven discard dumps was 2.01 mg.dm^{-3} but the non-outlier range was 0.12 to 2.43 mg.dm^{-3} (25-75% quartiles). The soluble iron concentration was elevated in the topsoil of Breyton and Witbank dump. The soluble concentration of iron increased in the topsoil of Witbank dumps from 0.08 to 11.85 mg.dm^{-3}. According to Mengel and Kirby (1987) iron

solubility is highly pH-dependent and precipitates as $Fe(OH)_x$ oxides if the pH rises above 7. Iron also readily forms organic chelates and complexes with organic compounds increasing its solubility. In this regard siderophores play a critical role as iron chelates. The application of manure to well-drained soils to increase the organic content may also be useful to improve the availability of iron. Other factors that could influence iron availability is a to high bicarbonate concentration, the application of only NO_3 containing fertilisers (Havlin et al. 1999) in already alkaline soils and elevated phosphorus. Most of the studies regarding iron deficiencies have been published for agricultural crops and the role of Fe in natural grasslands is unexplored.

The average soluble manganese values, on all dumps except for Newcastle, were lower than 1 $mg.dm^{-3}$. The soluble magnesium in cover soil samples was on average 4.44 $mg.dm^{-3}$, 6.46 $mg.dm^{-3}$ and 2.34 $mg.dm^{-3}$ for 2002, 2001 and 2002 but concentrations in excess of 20 $mg.dm^{-3}$ was measured on the Newcastle dump. The median pH taken from the 1:2 water extractant of cover soil samples at Newcastle over the three years was 5.06, but pH-values as low as 3.8 were measured. Cummings and Elliott (1991) indicate concentrations of 5ppm in an aqueous solution as phyto-toxic and Efroymson et al. (1997) 4$mg.dm^{-3}$ as phyto-toxic. In light of the acidic cover soil samples measured at Newcastle and the indicated toxicity guidelines it is potentially possible that the cover soil had phyto-toxic concentrations of manganese. The toxicity was probably not due to manganese pollution but due to acidic cover soil. The average pH of the cover soil increased from 4.6 in 2001 to 6.4 in 2002 after an 11$ton.ha^{-1}$ lime application thereby decreasing the manganese concentration from 5.5 to 2.3 $mg.dm^{-3}$ (Table 5).

The current soil nutrient status of the topsoil was statistically compared with the Mann Whitney U-test with soil samples collected from semi-natural grasslands in the vicinity of the mine. Table 6 expressed the ratio between the cover soil and background soil value for a particular chemical property as well as the level of significance indicated with the Mann Whitney U-test. The Mann Whitney U-test was used since the data were skewed and characterised by heterogeneous variances (even after application of the log transformation). The Mann Whitney U-test assessed the hypothesis that both sampling groups were taken from soils with similar nutrient properties.

The Bray extractable phosphorus was 20X higher in the cover soil of the Breyton dump in comparison to the grassland soils (Table 6). With the exception of Zn and Mn all other samples were similar or higher than the average measured for the

background values (Table 3 and 4). The organic carbon in the topsoil was also comparable to the background values (Table 6). The organic carbon was measured in 2002 for the six dumps. The median organic carbon was 0.9% and the average 1.41 ±1.34%. The highest organic carbon was measured in the cover soil of Breyton (2.445 ± 0.898%) and Ogies (3.35 ±2.29%) and compared favourably with the organic carbon measured in the background grassland soil samples (2.42 ±1.47%). The dumps at Witbank and Ermelo had on average the lowest organic carbon levels (organic carbon < 0.5%). The cover soil on the dump at Newcastle had an organic carbon content of 1.56 ±0.88%. Organic carbon analysis is one of the most frequent analyses conducted in post-mine rehabilitation studies. A too high organic carbon content can, however, be indicative as contamination with coal residues.

The cover soil on the discard dump near Ogies was characterised by a statistically significant (p< 0.001) elevated Bray-extractable phosphorus (Table 6). The lower CEC, due to the more sandy texture of the topsoil, resulted in lower soil fertility in comparison to the background samples and Breyton dump. In particularly magnesium was lower than that measured for the background samples. Micro-elements were particularly lower than background samples (Table 6).

The nutrient status of cover soil on the two Witbank dumps were lower in comparison with the background samples and Ogies and Breyton dump. The extractable macro-elements, particularly magnesium, were elevated above background samples. Soluble nitrate and ammonium compared well with background values on the Witbank dumps. A low sulphate in the cover soil indicates that little salt precipitation, due to capillary action are evident. The available Bray-extractable phosphorus was, less than half of that measured for the background samples. The phosphorus values, however, increased on the Witbank dumps from less than 15 to over 30 mg.kg^{-1} (Table 5).

2.4.   Multivariate analysis

Figure 2 presents a biplot from a standardised and centred PCA of both cover soil samples and natural grassland samples to indicate their relationship and the chemical variables that illustrated the biggest variance among dumps. The eigen-values for the first two axes were respectively 0.29 and 0.19 and therefore presented 48% of the total variance in the dataset. Figure 2 indicates the first PCA axis

presented a gradient in electrical conductivity. Specifically associated with electrical conductivity were 1:2 water extractable sulphate, calcium and magnesium (Figure 2).

Table 7: Ordination statistics (eigen-values, species environmental correlation and interest correlations between environmental variables and "species" axes) from partial RDA conducted between cover soil chemical data and independent factors that could have influenced the chemical properties of the cover soil on rehabilitated discard dumps.

Statistics	Description	1st axis	2nd axis
Eigen-values		0.05	0.03
Species environmental correlation		0.62	0.54
Manure	tonne.ha^{-1} applied	-0.32	-0.32
$CaNO_3$	Fertiliser	0.02	-0.44
KNO_3	Fertiliser	0.08	-0.25
Lime	Calcitic and dolomitic lime	0.33	-0.08
Surface	Nominal variable slope/ surface (0/1)	0.34	-0.03
Year	Survey year (temporal gradient)	0.40	-0.32
Clay	Percentage clay	N.S.	
Depth	Effective cover depth measured in 2003	N.S.	
Super Phosphate	Super Phosphate fertilisers	N.S.	
Slit	Percentage silt fraction in topsoil	N.S.	

The second ordination axis presented a base saturation gradient of calcium, magnesium and potassium as well as Bray-1 extractable phosphorus. Most soil samples were closely associated in the middle of the diagram indicating that the soil chemical characteristics were very similar and were distributed along the second ordination diagram. The PCA-diagram indicates that the Newcastle dump (◄) had an abnormal concentration of sulphate salts. The Breyton dump (X) had in comparison with the remainder of the cover soil a high soil base saturation and high Bray-1 extractable phosphorus concentrations. The grassland soils incorporated as reference soils were situated to the bottom of the second ordination diagram. The close proximity of the background samples indicated that the nutrient status of the majority of cover soil samples at the surface was comparable to the background samples. Figure 2 further indicates no relationship between extractable calcium and magnesium and soluble calcium and magnesium. A close correlation existed between soluble potassium and extractable potassium. Soil pH was not closely

associated with the first or second axis and was therefore not a principle component within the PCA.
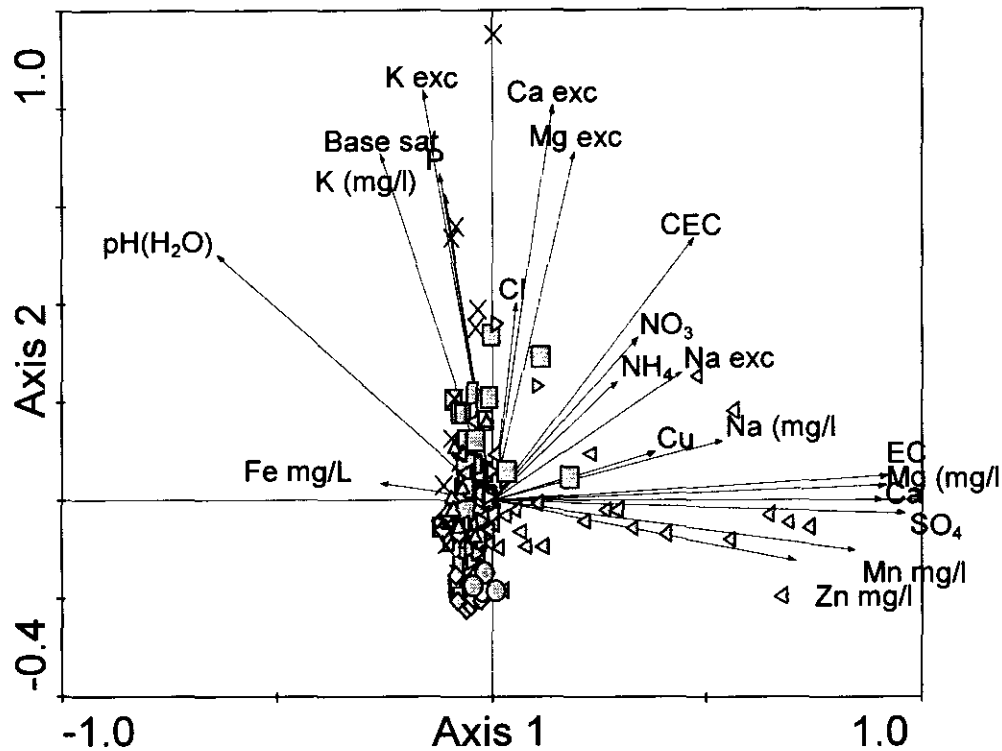
Figure 2. PCA biplot of cover soil samples and natural grassland samples to indicate the relationship in soil chemical properties.

The potential effect of fertiliser treatment on soil chemical properties (Tables 3-5) of cover soil was investigated with a partial Redundancy Analysis (RDA). RDA can be considered a linear ordination model and is related to Principle Component Analysis (PCA) as well as multivariate regression. The result from the partial RDA is portrayed in a biplot diagram with the dependent or independent variables as vectors (arrows) and the sample sites as points (Figure 3). The aim of an RDA is to directly relate the dependent variable to the independent factors. The statistical results from the partial RDA is summarised in Table 7.
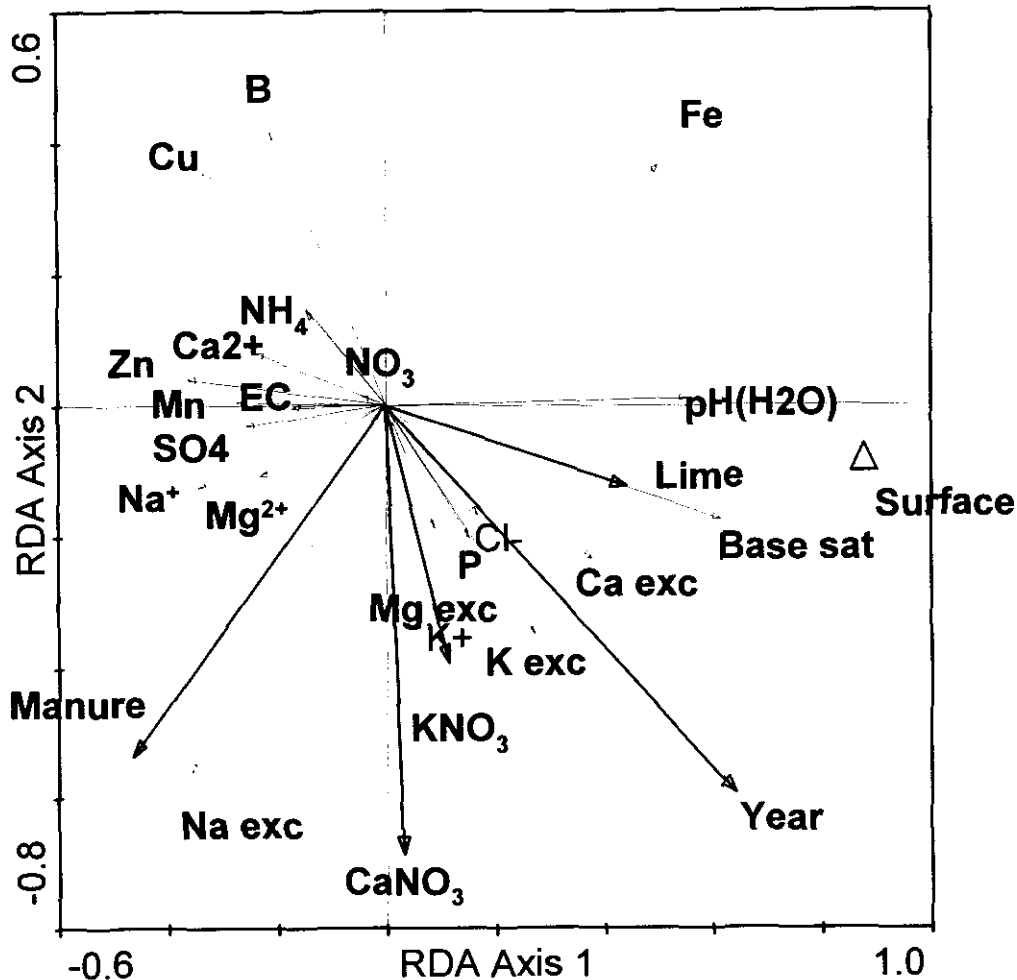
Figure 3. Partial RDA biplot between soil chemical properties of the cover soil and fertilisation inputs, soil cation exchange capacity during the three years. The dumps on which the samples were collected were used as co-variables and were included as binary data.

The results from the RDA biplot can be interpreted as follows. The first two eigen-values for the first two axes were 0.05 and 0.03 (Table 7). The sum of all the eigen-values was 0.722 (the dumps therefore accounted for 0.278 of the total variance). The sum of all the canonical eigen-values (therefore after fitting the independent variables) was 0.138. The quality of the display can be calculated from the statistics (Table 7). The first two canonical axes explained 58.7% of the fitted dependent data to the soil chemical data, but only 11.2% of the variance in the soil chemical data. The RDA-analysis with the selected independent factors also explained 19.11% of the possible variances. The relationship between the selected independent factors and the dependent soil chemical data can be determined by investigating the

ordination interset correlation between selected independent factors (environmental) and dependent variable (species) axes as well as the dependent-independent (species-environmental correlation) correlation for each axis. The selected independent variables correlated 62.3% and 54.4% with the first two dependent ordination axes.

According to interset correlations the temporal (year gradient) related best with the first ordination axis. The RDA-statistics further indicated that the nominal variable, slope/surface was related to the first axis. The application of $CaNO_3$ and manure correlated best with the second ordination axis. The first ordination axis can therefore be described as a temporal gradient and the second ordination axis as a fertilisation gradient.

Cover-soil pH and base saturation were positively correlated with lime application and the temporal gradient (Figure 3). Extractable calcium, magnesium and potassium were positively related to the temporal gradient as well as the application of $CaNO_3$, KNO_3 and $MgNO_3$. A positive relationship also existed between Bray-1 extractable phosphorus and the application of $CaNO_3$, KNO_3 and $MgNO_3$. The occurrence of the nominal variable, slope/surface suggests that cover-soil pH was more alkaline on the top of the dumps than on the slopes. Extractable sodium was positively associated with the application of manure but water-soluble iron was negatively associated with manure. The negative relationship between manure application and soluble iron is interesting since manure would have added considerable amounts of iron to the system. Most of the remainder of the soil chemical properties, including SO_4, Mn, Zn, and electrical conductivity, was negatively related to soil pH (concentrations higher under more acidic growth conditions). Soluble nitrate contributed little to explain the variance in the RDA and therefore was not correlated to any independent variables or did not vary among samples taken.

2.5. Conclusion

From the results of the study it can be concluded that the soil nutrient properties of the cover-soils surface is conducive for vegetation growth. Phosphorus supply was a potential problem but the availability did increase during the three-year period. The nitrogen application to the soil is slightly low following conventional pasture practices. The applications of nitrate-based fertilisers sustained the available nitrate and

ammonium concentrations. The sole application of nitrate would have resulted in a reduction of soluble protein in plant tissue since most of the nitrogen will be accumulated in the plant in the form of nitrate (Lasa *et al.*, 2001). An alternative method for incorporating nitrogen back into the rehabilitated system is by establishing legumes. The role of legume species to improve nitrogen accumulation and improved nutrient cycling has been found highly beneficial (Palmer *et al.*, 1986 and Peoples & Baldock, 2001). The lack of persistence of legumes on rehabilitated land as well as the potential for bloat has resulted in less confidence in the role of legumes to improve cover soil fertility and nutrient cycling on rehabilitated land.

Mineralogically, kaolinite is the dominant clay mineral in the cover material. This has certain implications for soil fertility. The CEC of kaolinite is comparably small and limits the macro-element retention capacity of the cover soil. Applications of manure can, however, improve the CEC. Nell and Steenekamp (1998) found a higher than expected CEC of 55 $cmol_c.kg^{-1}$ which they attributed to an abnormal carbon content of 27.28%.

Soil compaction was noted on two of the dumps. Compaction was, however, not quantified. The occurrence of crust formation and compaction was particularly associated with cover soils originating from apedal soils with a moderate (±20%) clay and silt content. Soil compaction and hard setting was a common problem on rehabilitated open-cast land investigated by Nell and Steenekamp (1998). The problem of high soil-bulk densities can to a certain extent be rectified by promoting a healthy root formation and organic matter.

A consistent tendency within the data was the increase in calcium, magnesium and potassium within the cover soils. The RDA also confirmed this. Ammonium acetate extractable bases were particularly strongly associated with fertilisers applied and reflect the nutrient status better than the 1:2 water extraction. Continual input of calcium and magnesium as calcitic/dolomitic lime and as nitrates salts increased the macro element concentrations. This is particularly obvious from the ammonium acetate analysis. Although the soluble fraction was not subtracted from the ammonium acetate analysis to provide a correct assessment of the base saturation it do indicate an increase in the base saturation overall. Most of the exchange positions have therefore been saturated with macro elements particularly calcium and magnesium.

The Bray-extractable phosphorus did not respond to the application of super phosphate because soil analysis did not reflect the input of super phosphate. The RDA indicates a tendency of higher Bray-extractable phosphate with higher applications of nitrate-based fertilisers as well as lime. This was in line with the objectives of the fertilisation programme.

Nitrate based fertilisers was used with the clear objective to keep the rhizosphere pH as neutral as possible and not to further exacerbate the potential acidity of the cover soil. This is especially true for the rehabilitated discard dump near Newcastle. According to Venter (2003) ammonium nitrate requires 0.57 $CaCO_3$ kg.kg fertiliser^{-1} to neutralise the potential acidity by applying N as ammonium nitrate. Although Rethman (1987) reported that lime ammonium nitrate and ammonium sulphate were superior to potassium nitrate international literature indicates that the type of nitrogen uptake depend among other factors on soil pH and temperature (Mengel and Kirby, 1986). Ammonium application is regarded as a factor in best management practices since ammonium is not subjected to leaching and denitrification loss (Lasa *et al.*, 2001).

Assuming that the applied nitrate-based fertilisers are relatively pure and that the approximate total nitrogen of the kraal manure is 0.8% (measured from manure samples used for amelioration of the dumps) the applied nitrogen can be calculated. Based on this information the dumps received on average 85, 59 and 34 kg/ton N both in the form of organic and inorganic nitrogen for 2000, 2001 and 2002. Pieterse and Rethman (1995) obtained significant increases in production when applications of 80 kg N.ha^{-1} are applied to *Digitaria eriantha*. Venter (2003) recommends a minimum input of 60 kg N.ha^{-1} for a low yield production (4 ton.ha^{-1}).

Although the sulphate concentrations did not increase during the study period it was higher than values measured in natural grassland sites. This suggests two scenarios. Firstly, contaminated cover soil used was effected by surrounding mining activities or that to a limited extent sulphate migration due to capillary movement of soil water has occurred. With the exception of one dump the elevated sulphate concentrations were not problematic and did not result in an unacceptable high electrical conductivity (salinity).

Phyto-toxicity of micro-elements was in general not a potential problem on all but the Newcastle dump. Acidic soil conditions (pH< 6) resulted in elevated manganese concentrations. Although the cover soil's pH at the Breyton dump was higher than

background samples, the corresponding soluble Fe was 4x higher. Soluble zinc and copper concentrations were generally low.

3. TOPSOIL DEGRADATION ON REHABILITATED DISCARD DUMPS WITH SPECIFIC REFERENCE TO SALINITY AND ACIDITY

3.1. Introduction

According to Bell (1996) the biggest concern when rehabilitating colliery spoil heaps are the reduction of slope-steepness, acidity and spontaneous combustion due to exothermic reactions. The effective management of these factors during rehabilitation is critical for the rehabilitation process to be successful. The importance of slope steepness and length; in a variety of climates, on vegetation establishment and water infiltration were studied by Van Wyk (1994). The process of acidification due to pyrite oxidation in spoil heaps is also well studied and thorough discussions have been given by Backes et al. (1986), Kent (1982) and Bell (1996). According to Backes et al. (1986) pyrite oxidation occurs via two pathways, either through the addition of oxygen or ferric ions. Backes et al. (1986) further determined that pH and the solubility of iron play an important role in governing acid release. Below a pH of 4, ferrous ions are bacterially catalysed to ferric ions. A review of the role of bacteria in the process of sulphide oxidation in coal discard dumps has been given by Loos et al. (2000) who found a variety of bacteria in acid discard material. Further characteristics of the coal discard that could influence its acidification potential are the amount of carbonate/calcite material present. Calcitic compounds can buffer and neutralise the acidification process. It is therefore recommended to investigate the carbonate /pyrite ratio to determine the acid neutralisation capacity of the material (Kent 1982). Bell et al. (2001) reported high pyrite concentrations in coal-mines in the vicinity of Witbank. The acidification of coal spoils in the Mpumalanga Highveld generally varies, from west to east. Spoil material to the west, in the region of Kriel, is predominantly neutral to alkaline whereas the spoil material associated with coal in the Witbank and Middleburg region is acidic (Nell and Steenekamp, 1998). Under normal oxidation regimes 4 mol of H^+ will be released from a mol of pyrite (Backes et al., 1986).

Nell and Steenekamp (1998) found high salinity mostly in carbolithic and arenolithic spoil material. Mainly excessive levels of sulphate salts caused salinity and electrical conductivity values as high as 1076 $mS.m^{-1}$ was measured for spoil material. Sodicity is an infrequent problem and the median sodium content of spoils was

reported as 0.13 $cmol_c.kg^{-1}$ (29.9 $mg.kg^{-1}$). Ultimately the geological origin will determine the chemical characteristics of spoil material.

Wates & Rykaart (1999) have experimentally evaluated the performance of natural soil covers to restrict water flow to discard material. Among other aspects Wates & Rykaart (1999) concluded that vegetation of uncovered spoils has no effect in reducing outflow, single-layered soils is as effective as double-layered soils to reduce outflow and steeply sloped cells resulted in lower outflow. Loos *et al.* (2000) concluded that although single-layered cover layers reduce outflow it could not prevent acidification of the underlying discard. A cover layer of 700 mm from an Avalon soil type could not prevent the slow acidification of waste (Loos *et al.*, 2000). Wates and Rykaart (1999) proposed the effective compaction of discard, poor structured clay soils (with shrink and swell capabilities) should be avoided as cover material. Maintenance of cover material would be highly likely and funds must be allocated for this during the rehabilitation and after-care phase. The occurrence of acidification of discard material after placement of cover soil needs to be monitored from time to time (Loos *et al.*, 2000) since acidic could become a problem.

Literature indicates how acidification occurs and the factors controlling it. Management strategies to control acidity after rehabilitation have also been suggested. The effect of coal discard on cover soil acidity and salinity after rehabilitation has, however, not been evaluated. That it could influence the success of the rehabilitation process is indicated. Case studies are needed to evaluate present rehabilitation practices success and shortcomings. Regular monitoring and evaluation studies could give valuable advice to improve further rehabilitation practices.

3.2.   Aim and objectives

Topsoil quality is a priority to ensure the establishment of a self-sustaining vegetation cover. This study evaluates the occurrence of acidification and salinisation in the cover soil and underlying discard to assess the potential of vegetation regression on rehabilitated discard.

The study tested two hypotheses under the present management strategy.

a) An increase in soluble salts in the cover soil due to neutralisation of acids developed from pyrite oxidation. To test the hypothesis the study compared the current levels of soluble salts (measured as electrical conductivity) and sulphate levels within the cover soil in comparison with background soil.

b) The current maintenance practices success to control acidification from pyrite oxidation and natural leaching within the cover soil. To test the second hypothesis the study compares the cover soils pH within the cover soil at three sampling depths in comparison with background samples.

The study also presents results obtained over a four-year monitoring period. The interaction between soil chemical variables and soil acidity and salinity was investigated as well as the interaction between soil acidity and salinity with external independent factors.

3.3.   Materials and methods

3.3.1. Study area

The study was conducted on seven rehabilitated coal discard dumps with rehabilitation ages between 2 and 8 years (Figure 1). The most southern-situated site is to be found on the North-eastern border between Kwa-Zulu Natal and the Mpumalanga Province near the town of Newcastle. The most easterly-situated dumps were situated near the towns of Ermelo and Breyton. Two of the dumps were situated in Witbank. The smallest of the seven dumps was situated to the west of Witbank near the town Ogies. Chapter 2 of this dissertation gave a detailed discussion on the rehabilitation, maintenance practices and vegetation of the rehabilitated dumps.

3.3.2. Soil sampling

The topsoil on the seven rehabilitated dumps was sampled during July/August in 2000, 2001, 2002 and 2003 as part of the regular monitoring and fertilisation programme. In August 2002 and in March 2003 the topsoil surface, coal-soil contact zone as well as the soil above the contact zone and the coal beneath the contact zone was sampled. The sampling of the coal samples with a soil auger due to its

coarseness and compaction was at best difficult and the samples into the coal did not extend deeper than 100mm.

Acidity and salinity was quantified by measuring the saturated past pH and electrical conductivity of the surface topsoil layers, the soil contact zone with the coal and the coal at selected sites.

The 1:2 v/v water extractable and ammonium acetate exchangeable calcium, magnesium, potassium and sodium were also determined. The data were used to calculate the exchangeable sodium percentage (ESP)[1]. The percentage exchangeable cations was calculated by subtracting the water soluble fraction determined from the 1:2 water analysis from the extractable fraction determined by the ammonium acetate analysis. A 1:2 water extraction procedure was used to determine the soluble sulphate and bicarbonate concentrations.

3.3.3. Soil chemical analysis

All soil chemical analyses were conducted at the soil laboratory of EKO REHAB. The 1:2 (v/v) extraction procedure as described by Rhoads (1982) was used to determine the water-soluble concentration of cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+). Quantification was done by means of atomic absorption spectrophotometry with a Spectr. AA – 250 (Varian, Australia) (Ramiriz-Munoz, 1968).

The sulphate concentration was determined with an Ion Chromatograph (Metrohm 761, Switzerland). The bicarbonate content of the media extract was determined by the potentiometric titration method with a pH end-point of 4.5 using a standard 0.005M HCl-solution (Skougstad et al., 1979).

Exchangeable bases were determined using a Spectr. AA-250 (Varian, Australia) following extraction with ammonium acetate solution (Thomas, 1982).

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[1] $ESR = \dfrac{Na^+}{Ca^{2+} + Mg^{2+}}$ (all units in $cmol_c.kg^{-1}$)

The pH (water) was determined by adding 50 ml deionised water to 20 g medium. The suspension pH was measured with a calibrated pH/conductivity meter (Radiometer pHM 80, Copenhagen). The supernatant for determining the electrical conductivity was prepared by adding 50 ml of deionised water to 50 g of medium. The electrical conductivity of the supernatant was measured with a WTW LF92 conductivity meter.

The study also presents extractable acidity values obtained from KCl-extractions and NaOH-titration (Thomas, 1982).

3.3.4. Data analysis

Data were analysed with STATISTICA for Windows (Statsoft 2003). Data were foremost compared by means of descriptive statistics in box and whisker plots. The centre points in the box and whisker plots indicate the average for the group, boxes indicate standard error deviation from the average and whiskers indicate the non-outlier dispersion. Points outside the whiskers in the box's and whisker plots indicate extreme or outlier values. All box and whisker plots conformed to this standard.

The measured pH and log-transformed electrical conductivity values from the cover soil surface, the subsoil and coal layer were compared with One Way ANOVA. The Kruskal Wallis ANOVA was employed where data did not conform to the assumptions of normality and homogenous variances. The between-group differences among non-parametric data were compared using a multiple comparison of mean of ranks (Siegel & Castellan, 1988) in STATISTICA for Windows.

Pearson's correlations were used to investigate the linear relationship between soil chemical variables measured for the cover soil surface.

Multiple regression was employed to relate independent variable (soil-clay mineralogy, cover-soil particle size distribution, fertiliser treatments and coal pH and electrical conductivity) to soil pH and log-transformed electrical conductivity. Pearson's correlations on independent variables were conducted to identify multi-collinearity among variables (r<0.7). Independent variables perceived as potentially multi-collinear were omitted from the analysis, for example sand, clay and silt, were found multicollinear and therefore only clay was included in the input variables.

3.4.   Results and discussion

The average percentage exchangeable sodium for all dumps was calculated less than 1%. After subtracting the soluble fraction from the extractable fraction 30% of the samples had 0% exchangeable sodium. Results therefore indicate that sodic conditions are not a potential problem because the exchangeable sodium was low in the soil samples collected during the 2000-2003 period.

3.4.1. Change in soil pH and electrical conductivity

The change in average soil pH (pH-saturated water extract) and pH (KCl-extract) on the surface of cover soils of six rehabilitated discard dumps measured over a period of four years is illustrated in Figure 4. The results indicate that pH-values remained constant for three of the six dumps. As can be expected the pH measured in the KCl-extract was slightly lower than the pH measured in the saturated water extract (Figure 4). The pH on the cover soil of the Newcastle dump had a high variability with a large number of outliers and extreme values (Figure 4). The Witbank and Newcastle dumps both experienced a drop in the water saturated paste pH during 2001. An application of 11ton/ha lime was sufficient to increase the cover soil pH from 5.110 to 6.103 at the Witbank dumps. The measured lime requirement for the dump during 2001 varied between 0 and 18.8 ton $CaCO_3.ha^{-1}$, the average being 4.05 ton.ha^{-1}. The Bethal dump had the most alkaline cover soil with an average water saturated pH of 7.75 ±0.42 and 7.57 ±0.44 for 2002 and 2003. The dump was rehabilitated during 2001, thus the lack in the data between 2000 and 2001. The dump with the most acidic cover soil had a saturated water extract pH of 5.55 ± 1.15, 5.11 ±0.91, 6.10 ±1.27 and 6.57 ±0.85 for the period 2000 to 2003.

The average pH for all dumps surveyed was respectively 6.35, 6.10, 6.87, and 7.11 for 2000-2003. The average values were slightly lower than the median values of 6.56, 6.38, 7.07 and 7.17. The minimum pH over the three-year period for the dumps surveyed for the cover soil was 3.7 and the maximum value 8.26. These were however extreme outlier values since the 25% quartile was 6.18 and the 75% quartile pH 7.47. The average and median values indicate an increase in pH on the dumps studied.

The changes in electrical conductivity during 2000-2003 on the six dumps are illustrated in Figure 5. The electrical conductivity remained relatively the same for the

Newcastle, Breyton and Bethal dumps (Figure 5). The electrical conductivity on the Witbank dump remained unchanged for 2000-2002 but increased from 22.5 ±8.313 to 88.333 ±21.360 (Figure 5). The increase was associated with an application of 5 ton.ha^{-1} kraal manure and 5 ton.ha^{-1} dolomitic lime. The average electrical conductivity measured for the cover-soil values for five of the six dumps was less than 100mS.m^{-1} during the sampling period of 2000 to 2003. The maximum electrical conductivity values were also less than 300 mS.m^{-1} except for one dump who's electrical conductivity values was in the magnitude of 300-470 mS.m^{-1}. The average electrical conductivity measured for the cover soil was 78.9 ±86.52 mS.m^{-1}. The median of 44.00 mS.m^{-1}, the 25% quartile of 30 mS.m^{-1} and 75% quartile of 82.5 mS.m^{-1} indicate that the frequency of electrical conductivity was low with a few high outlier values.

3.4.2. Soil salinisation and acidification on topsoil

Cover soil samples were collected from the subsoil, the contact zone between the coal discard and cover soil as well as from the underlying coal discard. The data were compared with soils collected in natural and semi-natural grasslands in the vicinity of the mines. To assist with interpretation the samples were divided into sandy soil (clay 7.7± 3.0%) samples and clay cover-soil samples (clay 31.7± 7.4%).

Figure 6 illustrates the electrical conductivity results from the discard dumps covered with a predominant sandy cover soil (clay 7.7± 3.0%). Eleven samples collected from the cover-soil surface, subsoil, contact and coal at three rehabilitated discard dumps were compared with 18 background soil samples. The effect of cover-soil depth was statistically significant (p< 0.001) for electrical conductivity but not for pH at the dumps covered by a sandy cover soil layer.
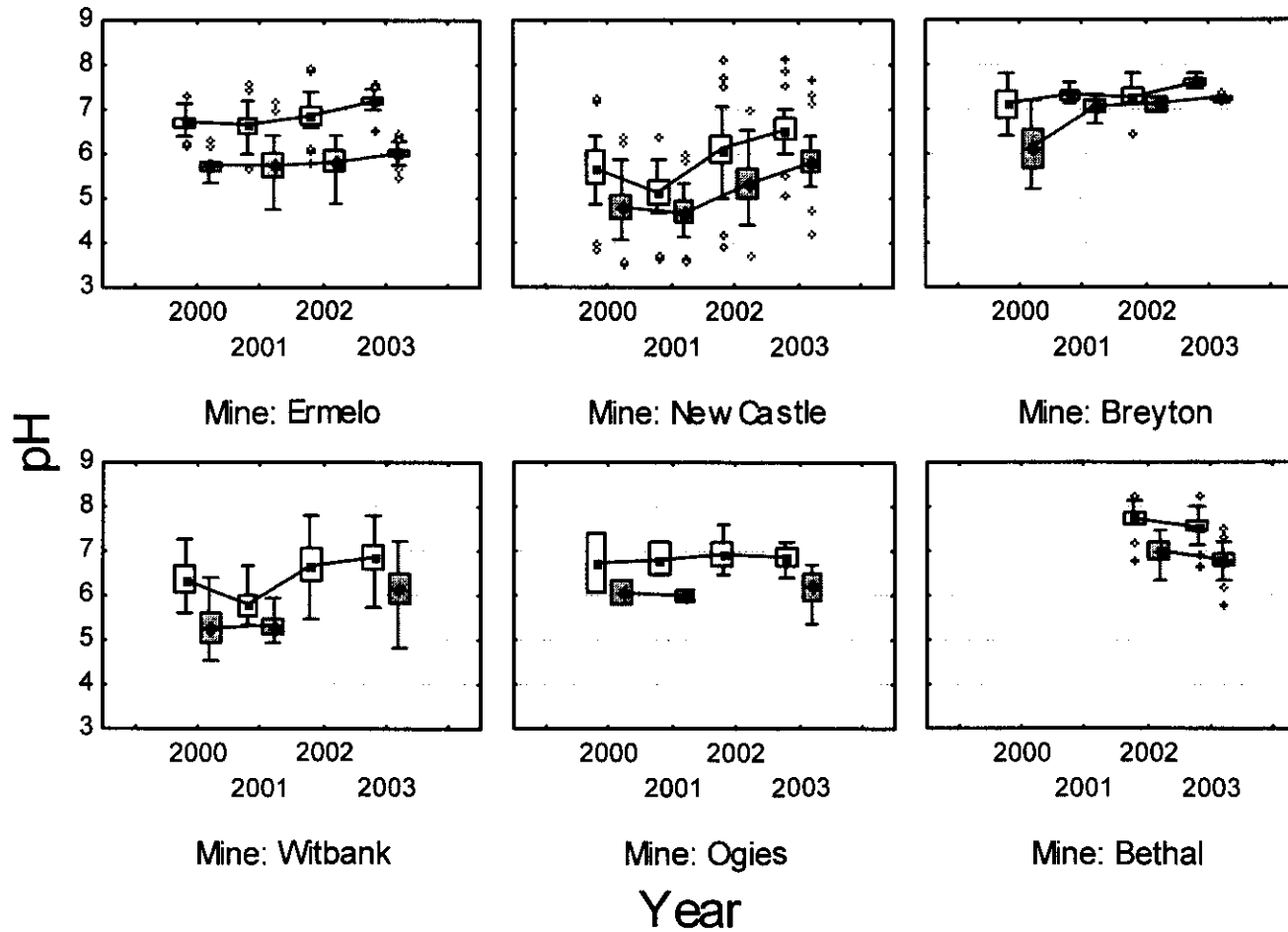
Figure 4. Change in saturated paste pH ■ and pH measured in a KCl-solution ♦ at six rehabilitated discard dumps. Box and Whisker plots indicate average, standard error deviation, non-outlier range and extreme values.
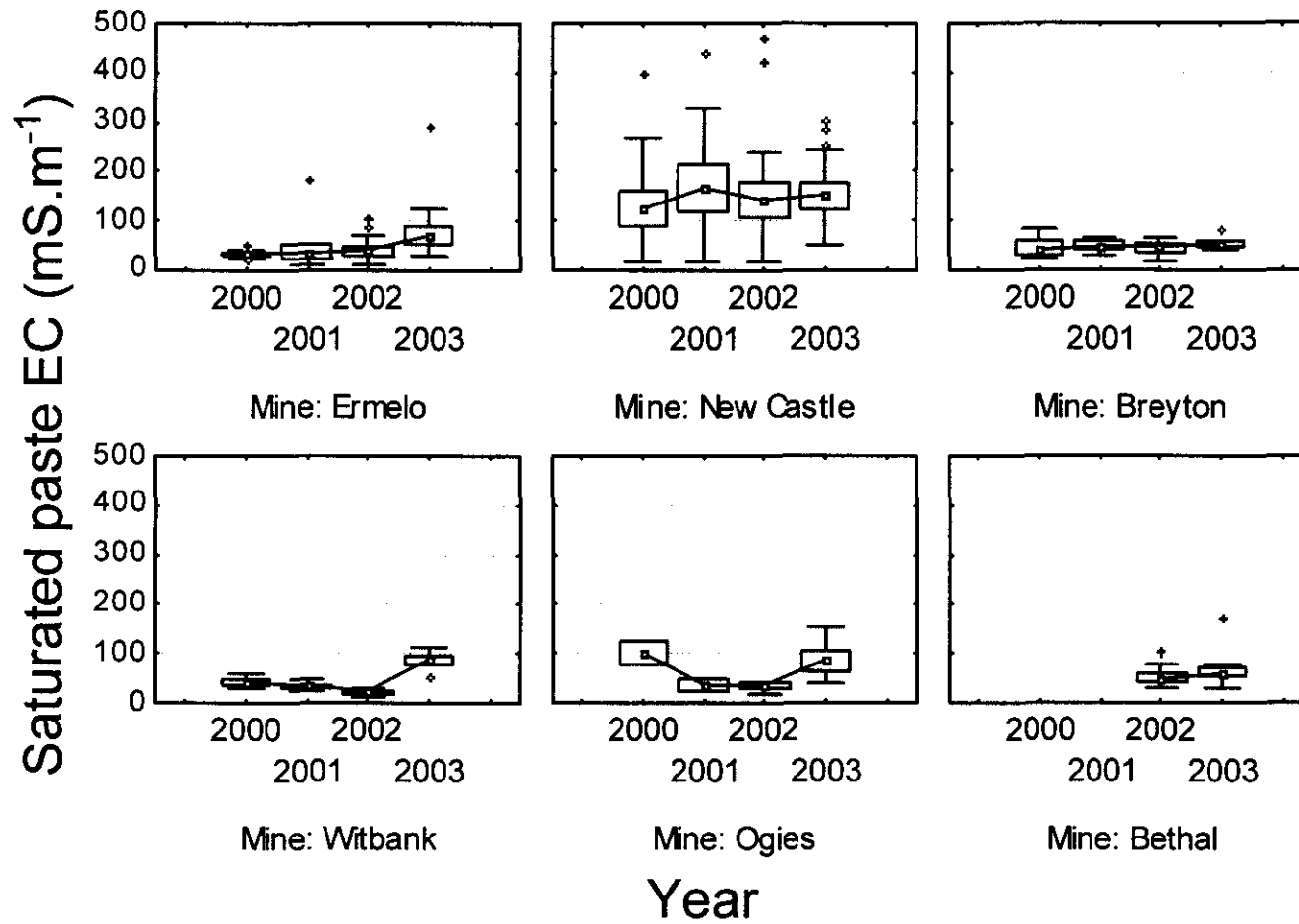
Figure 5. Change in saturated paste electrical conductivity (EC) at six rehabilitated discard dumps. Box and Whisker plots indicate average, standard error deviation, non-outlier range and extreme values.

The cover soil surface of the sandy dumps had a similar electrical conductivity to the control samples. The electrical conductivity of the subsoil and coal contact was higher in comparison with the surface of the cover-soil samples but not statistically significantly so. An increase in salinity is therefore noted with an increase in cover-soil depth (Figure 6). The cover soil salinity increased from 32.00 ±15.90 $mS.m^{-1}$ at the surface to 101.18 ±133.15 $mS.m^{-1}$ at the coal contact zone. The coal contact zone was measured in August 2002 and the subsoil and coal in April 2003. Both the soil contact zone (68.73 ±52.16 $mS.m^{-1}$) and subsoil (101.18 ±133.15 $mS.m^{-1}$) were expected to have similar values. The samples therefore indicate the dynamics at the contact zone regarding soluble salt concentrations. Seventy two percent of the coal samples had an electrical conductivity of 200 $mS.m^{-1}$ or more. The maximum electrical conductivity measured in the coal was 573 $mS.m^{-1}$. The electrical conductivity of the coal was significantly higher ($p< 0.001$) than the cover soil. What is also interesting is the increase in variability in electrical conductivity with depth.

Results from the saturated paste extract pH measurements at different depths on discard dumps covered by a sandy cover layer are compared in Figure 7. The effect of sampling depth on saturated paste pH was not significant. The data originated from samples collected on three discard dumps rehabilitated during 1998. In comparison with the electrical conductivity values, the pH remained similar with increase in depth. The average pH of the coal was measured as 6.43 ±1.03, which is slightly more alkaline than the control samples pH (average pH 6.05 ±1.08). The effect of liming can be observed in the higher average pH of the surface of the cover soil. The minimum and maximum pH measured for the coal discard samples were 4.05 to 7.65 and the minimum and maximum for the cover soil samples (all depths) were 4.65 to 7.65. Fifty percent of the thirty-three samples taken in the cover soil were in the range of 5.8 to 7.26.
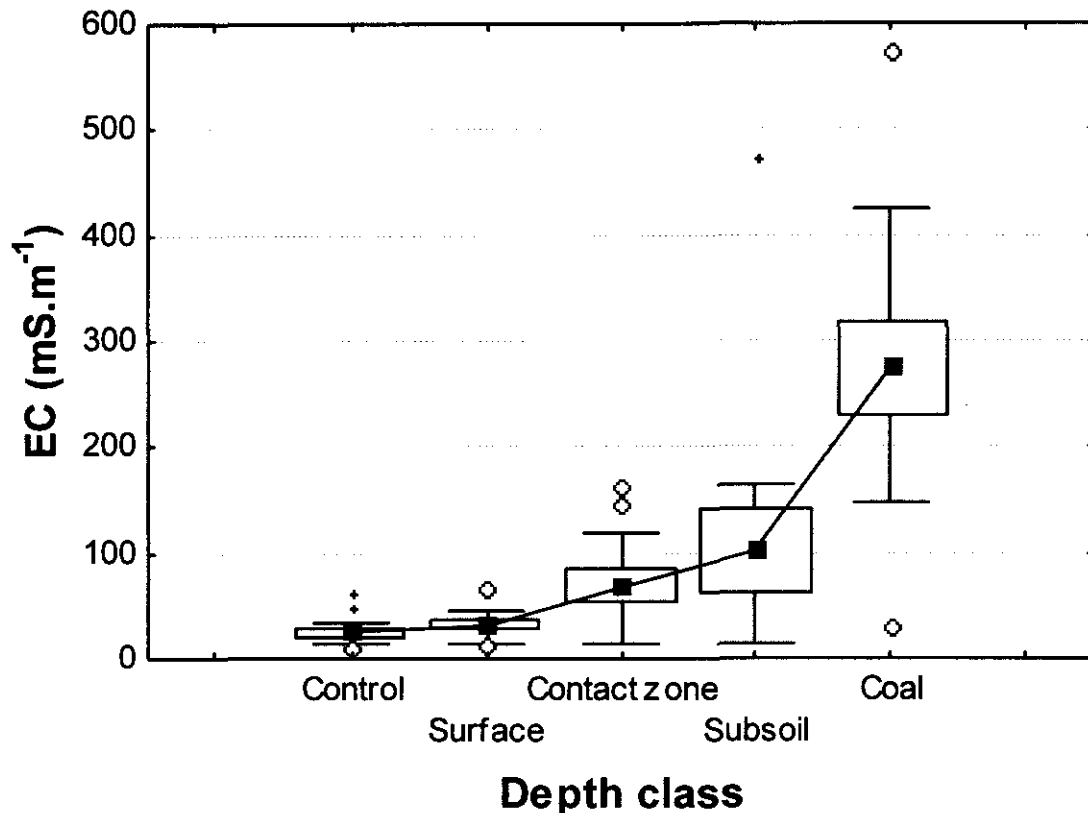
Figure 6. The salinity of topsoil at the surface soil, subsoil, contact zone and coal discard on rehabilitated dumps covered by a sandy-soil layer (clay <15%) in comparison with natural soil in the vicinity.

The effect of the coal discard on cover soil quality in terms of salinity and acidity was also investigated on a two-year old and eight year old rehabilitated dump covered with a cover soil layer with average clay percentages of 35 and 28% clay respectively. Seven samples collected from the cover-soil surface and cover soil-coal contact and six samples from the coal at one rehabilitated discard dump were compared with 18 background soil samples. The difference in topsoil electrical conductivity with depth on a two-year old rehabilitated dump is indicated in Figure 8. The two-year-old rehabilitated dump has a 500 mm cover soil layer placed on compacted coal discard. The coal discard was also limed before covering it with cover soil. Figure 8 presents a box plot indicating the average, standard error deviation and outlier range as well as extreme values measured on the surface, soil-coal contact subsoil and underlying coal. The effect of sampling depth was statistically significant for both pH and log-transformed electrical conductivity values.
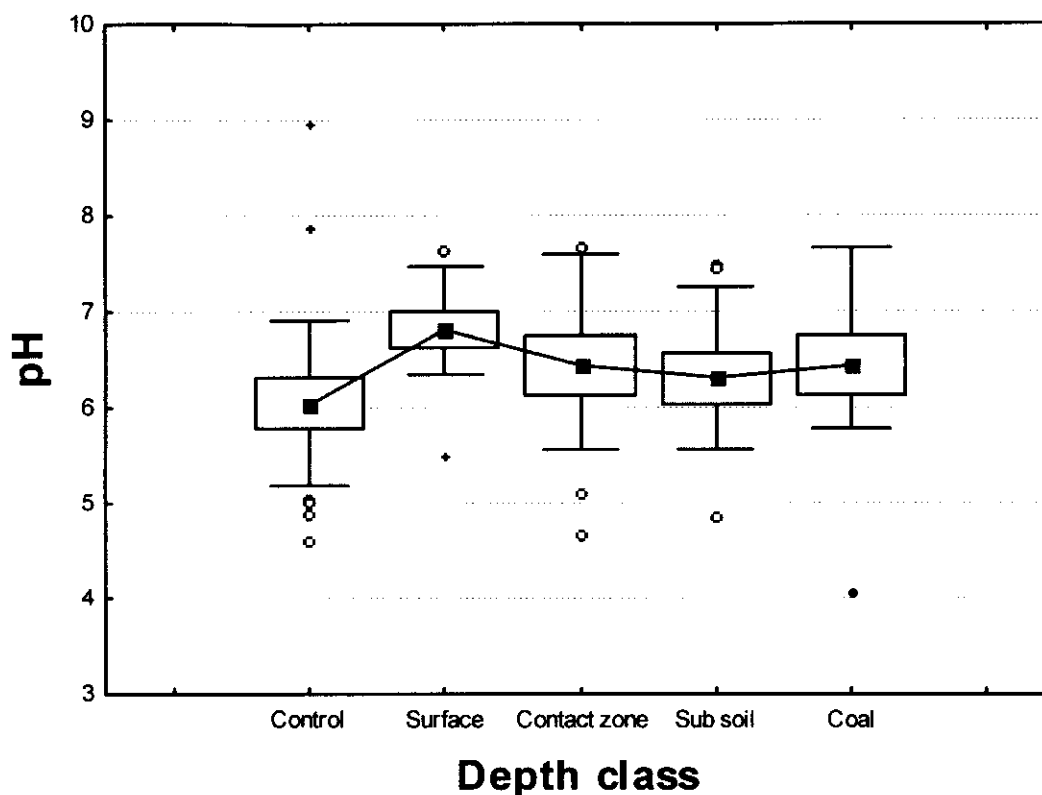
Figure 7. The acidity of topsoil measured as pH(H₂O) at the surface soil, subsoil, contact zone and coal discard on rehabilitated dumps covered by a sandy-soil layer (clay <15%) in comparison with natural soil in the vicinity.

The surface of the cover soil was similar to the natural background (EC ≈ 25 mS.m⁻¹) samples but the electrical conductivity increased significantly (p< 0.001) in the contact zone (EC 219.86 ±104.54) and subsoil (EC 197.00 ±176.66) in comparison with the background soil samples and cover soil surface (Figure 8). As in the sandy cover soil the variance within the samples increased in depth. The electrical conductivity of the coal discard samples was 437.67 ±130.75. The highest electrical conductivity measured in the cover soil was 493.00 mS.m⁻¹ and 666.00 mS.m⁻¹ in the coal.

The difference in saturated extract pH at different sampling depths is indicated in Figure 9. The background soil samples (p< 0.05) and cover soil surface (p<0.001) differed statistically significantly from the coal samples. The average soil pH at the surface (pH 6.84 ±0.82) of the cover soil was slightly higher than the control samples (pH 6.05 ±1.08). The average pH decreased with more than 1 unit from the surface to the subsoil (Figure 9). The saturated water extract pH at the contact zone was 4.95 ±1.12 and the subsoil sample 5.49 ±0.92. The 25% quartile pH for both samples was

less than 5. The minimum pH for the cover soil was 3.8 and that of the coal 4.04. Whereas the subsoil samples had pH-values of 6.5 and more, the pH of the coal was at maximum 4.9 and therefore considerably acidic. The acidification potential of the coal remained high after two years. As indicated by Loos *et al.* (2000) cover soil did not limit the potential of acidification of the underlying discard. Further acidification could therefore be expected.
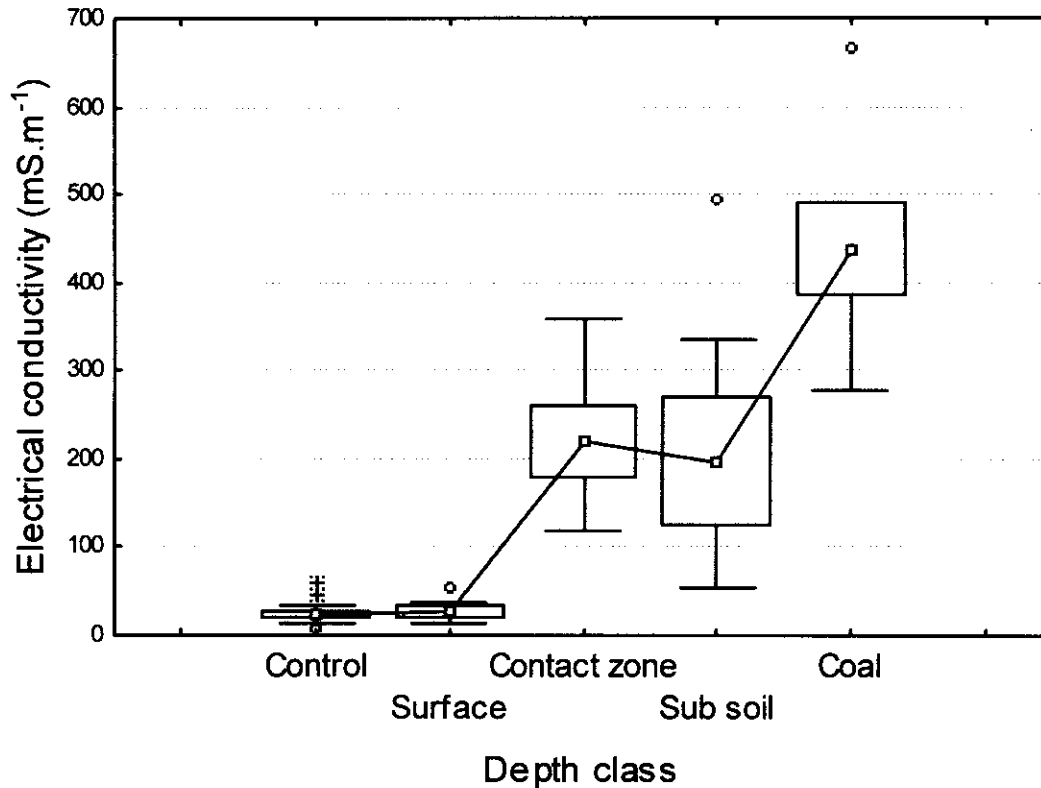
Figure 8. The salinity of topsoil at the surface soil, subsoil, contact zone and coal discard on two-year rehabilitated dumps covered by a clay soil layer (clay >15%) in comparison to natural soil in the vicinity.
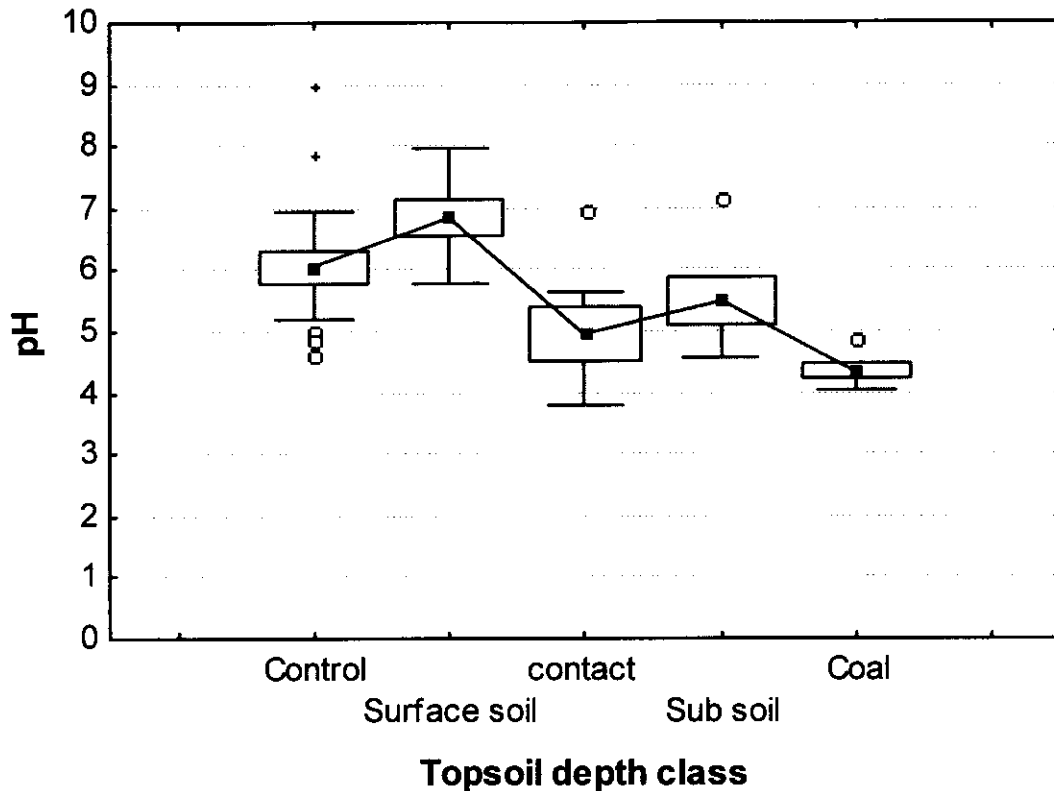
Figure 9. The acidity of topsoil at the surface soil, subsoil, contact zone and coal discard on two-year old rehabilitated dumps covered by a clay soil layer (clay >15%) in comparison to natural soil in the vicinity.

Seven samples collected from the cover soil surface and contact as well as eight samples from the subsoil and coal at an eight-year old rehabilitated discard dump with a 240mm cover-soil layer were compared with 18 background soil samples with regard to salinity and acidity (Figures 10 and 11).   A characteristic of both the electrical conductivity measurements and saturated pH samples were the broad non-outlier range (Figures 10 and 11).   The hetero-scedasticity of the data made parametric comparison of the data difficult and therefore the Kruskal Wallis ANOVA was used to test the effect of cover-soil depth on pH and electrical conductivity. The effect of cover-soil depth was statistically significant for pH ($p < 0.05$) and for electrical conductivity ($p < 0.001$).   A multiple comparison based on the mean of ranks indicated that the background soil samples pH was significantly higher than that measured for the cover soil layers in general and for the coal. Whereas the cover soil surface of the two other case studies was comparable to the background control samples this was not be the case for the eight-year old rehabilitated dump. The cover-soil surface had an average electrical conductivity of 121.4 ±95.67 $mS.m^{-1}$ in comparison with the average electrical

conductivity of 24.28 ±13.57 mS.m^{-1} of the control samples (Figure 10). The average electrical conductivity was 268.57 ±217.40 mS.m^{-1} and 201.38 ±144.10 mS.m^{-1} for the coal contact zone and subsoil. The salinity of the cover soil on the eight-year old dump could therefore effect grass species production. Species such as *Chloris gayana* and *Cynodon dactylon* are more tolerant to salinity and will be less affected at these higher salinity levels. *Chloris gayana* and *Cynodon dactylon* may be less affected or even stimulated due to a lack of competition in saline soils (Russel & Roberts, 1986). The persistence of saline and acidic conditions, although large quantities of organic material have been applied, can be explained by the soil's high clay content and the presence of smectite clay minerals. Although the Kruskal Wallis ANOVA indicated that the topsoil depth had a significant effect on topsoil electrical conductivity a multiple comparison of the sum of ranks failed to indicate significant differences.
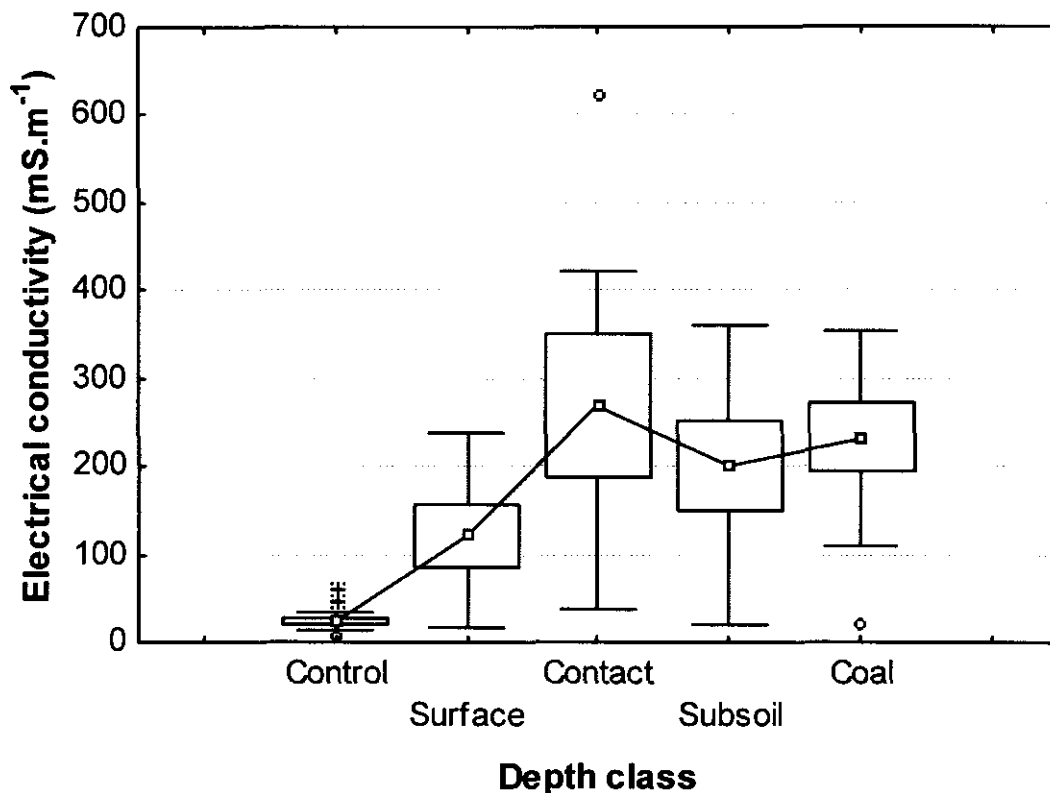
Figure 10. The salinity of topsoil at the surface soil, subsoil, contact zone and coal discard on eight-year rehabilitated dumps covered by a clay soil layer (clay >15%) in comparison with natural soil in the vicinity.

The pH between sampling depths was not statistically significant. The average pH for the cover soil surface as well as the subsoil was less than 6 and therefore consistently acidic. The surface pH was also similar (5.59±0.96) to the critical pH of 5.5 indicated by literature for effective plant growth. The median values were still lower than the average values calculated. The subsoil and coal contact zone had median values of 3.74 and 4.92. Essentially soil analyses indicated that the subsoil was more acidic than the coal discard.
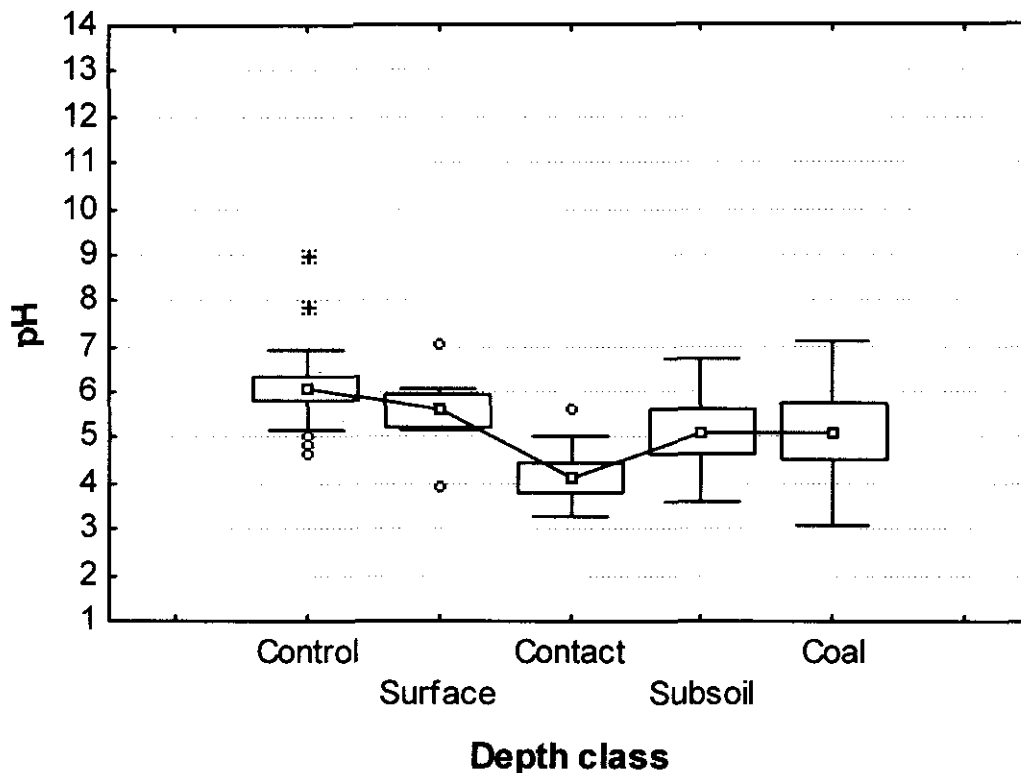

Figure 11. The acidity of topsoil at the surface soil, subsoil, contact zone and coal discard on two-year old rehabilitated dumps covered by a clay soil layer (clay >15%) in comparison with natural soil in the vicinity.

3.4.3. Soil properties and maintenance actions relation to salinity and acidification

The relationship between soil and management factors was analysed with Pearson's correlation with 2000-2003 data. Correlations was used to determine the relationship between pH and electrical conductivity measurements, determined with 1:2 water extract, saturated extract and KCl extract, to chemical properties of the cover soil surface. The effect of independent factors such as underlying coal acidity, cover soil

clay mineralogy and fertilisers applied was related with soil pH and log-transformed electrical conductivity. By potting the residuals against the expected normal values the assumption that the model parameters follows a normal distribution was tested. In both models for pH and electrical conductivity the residuals values did not deviate from the expected normal values. Table 8 summarises the most significant relationship of measured chemical variables with pH and electrical conductivity.

Soil electrical conductivity had an R = 0.99 correlation with sulphate concentration (Table 8 and Figure 12). Sulphate salts therefore contributed most to the salinity in the soil. A strong positive linear correlation was measured between electrical conductivity and the soluble magnesium (r= 0.94) and calcium (r= 0.94) as well as water-soluble manganese (r= 0.79) (Table 8). These correlations suggest that most of the salinity can be contributed to these ions. If the sulphate concentration is correlated with these a similar strong positive relationship is measured between the soluble sulphate and calcium (r=0.93), magnesium (r= 0.93) and manganese (r= 0.79). The soluble sodium concentration had a 0.40 linear correlation with soluble sulphate. According to Pearson's correlations (Table 8) no meaningful relationship existed between potassium and sulphate (r=-0.14) and therefore potassium did not contribute significantly to the salt content in the cover soil.

The soil pH was positively related to the bicarbonate concentration. Soil pH and bicarbonate seem to follow a logarithmic relationship (Figure 13). The equation indicates that a bicarbonate concentration of 20-30mg.dm^{-3} bicarbonate is sufficient to sustain a neutral pH and an increase in bicarbonate beyond this concentration would not contribute further to the buffer capacity of the soil. Cumming and Elliott (1991) recommend that the bicarbonate level of soil does not exceed 20 cmol$_c$.dm^{-3} (1220 mg.dm^{-3}) since it can result in calcium and magnesium deficiencies. A negative relationship was also observed between soil pH and soil sulphate concentration (Figure 14). The relationship indicates two aspects. That sulphuric acid is partially responsible for the acidity and indicates the product associated during and after sulphide neutralisation with the release of H$^+$. The oxidation process of sulphides suggests that sulphates are involved at different stadium of the oxidation process.

Table 8. Linear relationship between soil pH and soil electrical conductivity measured from 1:2 water extract, KCl as well as saturated water extract data collected during 2000-2003. Results from a Pearson's correlation. Variables with best fit are illustrated in Figure 10. The sampling size is 145.

		r(X,Y)	r^2	t	p	Constant	Slope	Constant	Slope
pH (1:2)	HCO_3 (mg/l)	0.73	0.53	12.72	0.000	-99.02	19.44	5.69	0.03
pH(KCl)	K (mg/l)	0.42	0.18	5.51	0.000	-35.32	8.97	5.52	0.02
pH(H_2O)	Zn (mg/l)	-0.56	0.31	-8.04	0.000	0.44	-0.06	6.90	-5.22
pH(H_2O)	SO_4 (mg/l)	-0.61	0.37	-9.16	0.000	1708.02	-223.59	7.04	0.00
pH(H_2O)	Mn (mg/l)	-0.60	0.36	-9.07	0.000	19.92	-2.80	6.85	-0.13
pH(H_{2o})	Ca (mg/l)	-0.57	0.32	-8.20	0.000	353.20	-45.22	7.05	-0.01
EC (1:2)	Zn (mg/l)	0.61	0.37	9.22	0.000	-0.01	0.09	0.39	4.37
EC (1:2)	SO_4 (mg/l)	0.99	0.98	77.83	0.000	-56.23	475.46	0.13	0.00
EC (1:2)	Na (mg/l)	0.43	0.18	5.64	0.000	4.38	11.56	0.39	0.02
EC (1:2)	Mn (mg/l)	0.79	0.63	15.49	0.000	-1.52	4.80	0.41	0.13
EC (1:2)	Mg (mg/l)	0.94	0.89	33.35	0.000	-6.29	56.37	0.16	0.02
EC (1:2)	Cu (mg/l)	0.40	0.16	5.15	0.000	0.02	0.01	0.27	12.02
EC (1:2)	Ca (mg/l)	0.94	0.88	31.95	0.000	-4.60	97.91	0.11	0.01
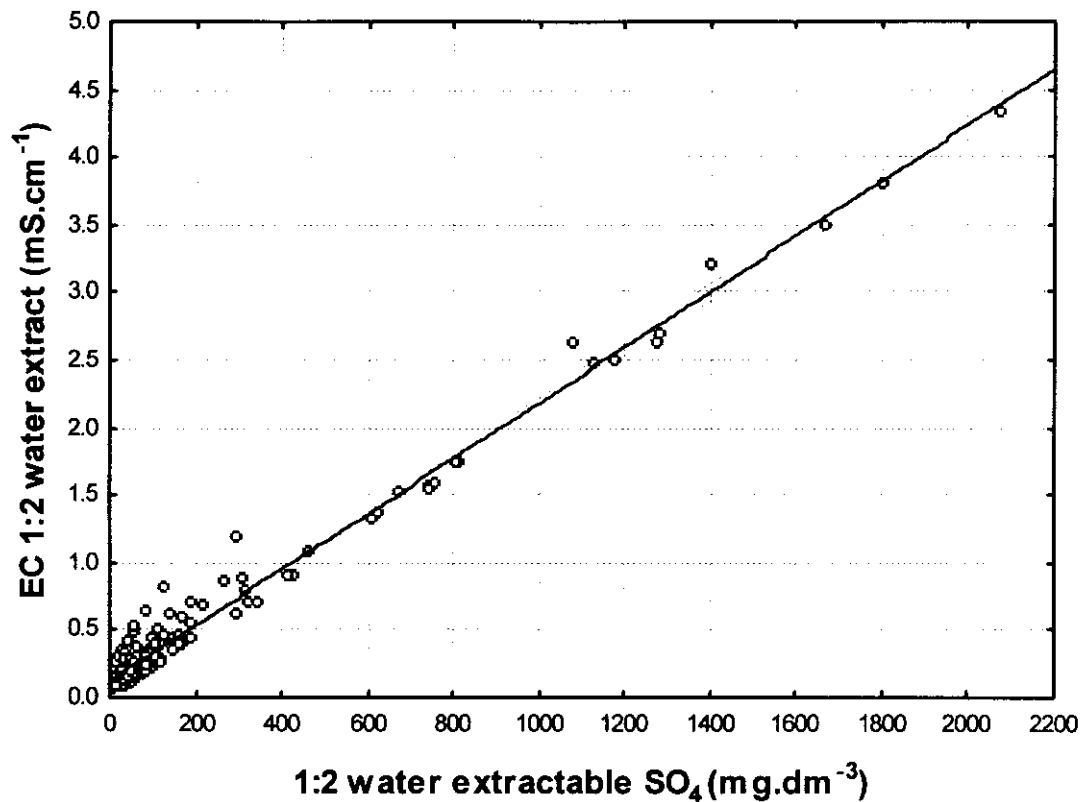
Figure 12. Linear relationship between electrical conductivity (EC) and sulphate (r= 0.99) measured in cover soil of rehabilitated discard dump (EC = 0.12855 +0.00205*SO₄).

The possible effect of independent variables such as coal pH, cover soils mineralogy and the applied fertilisers on soil salinity and acidity were tested with multiple regressions using 22 samples from which mineralogical data were available. The results from the regression are summarised in Table 9 and 10 for saturated-water extract pH and log transformed electrical conductivity. Variables were fit using a forward stepwise approach.

Within the variables tested (fifteen independent variables) soil pH was best related to inputs of $CaNO_3$ (β= 0.48), the underlying coal acidity (pH) (β= 0.32) as well as the percentage feldspar (β= 0.25). The multiple-regression model has a regression coefficient (R) of 0.678. A correlation matrix was also conducted between independent variables to identify collinear variables. The correlation matrix between the application of lime and $CaNO_3$ indicated a positive collinear relationship (r>0.7)
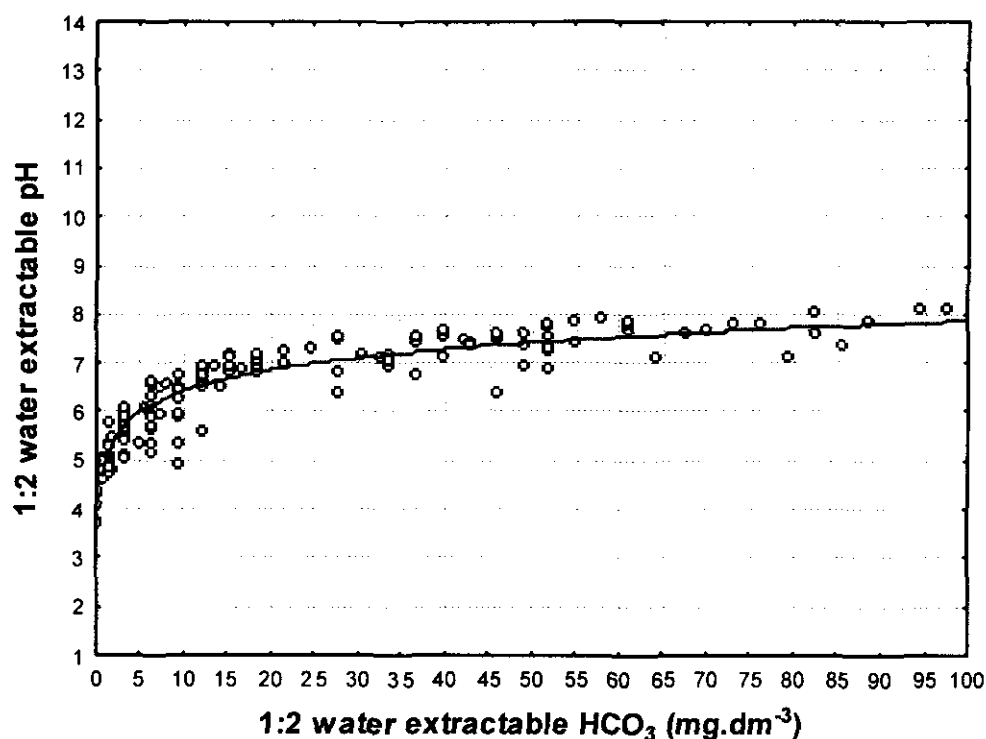
Figure 13. The logarithmic relationship between soil pH and bicarbonate concentrations (EC = 5.0001+1.4286*log HCO₃).

The forward stepwise-regression model for soil salinity indicated a statistically significant fit for lime application (β=1.280) and the percentage smectite in the cover soil (β=-0.634) (Table 10). Kaolinite percentage (β= -0.438), application of KNO₃ fertilisers (β= 0.652), the occurrence of calcite in the cover soil (β=0.197) and coal acidity (pH) (β=0.293) explained the remainder of the variance in the regression model (Table 9). The possible explanation for the higher salinity is the effect of the higher buffer capacity of soils high in clay minerals especially smectite. On the opposite, lime application was positively associated with salinity. Our results therefore seem to indicate that lime and application of KNO₃ were largely responsible for a higher cover soil surface salinity (Table 10). There, however, existed a 0.72 correlation between MgNO₃ and KNO₃ and therefore MgNO₃ could also contributed to higher salinity. Although cover-soil depth was included in the regression analysis it did not contribute sufficiently to be included in the model.
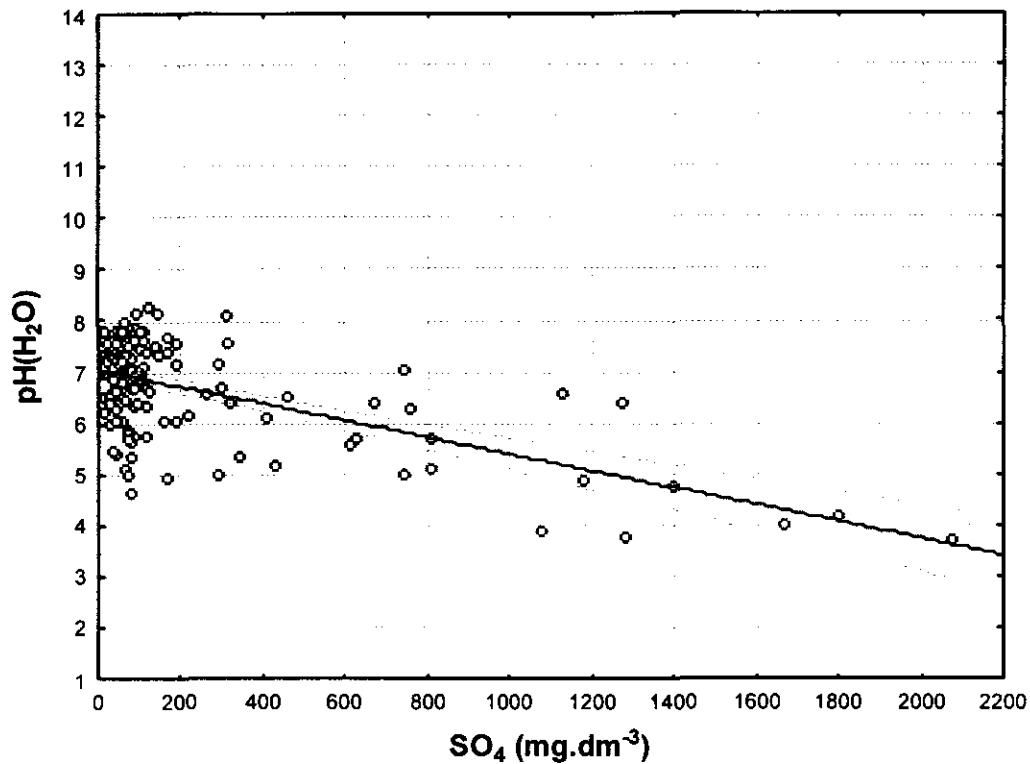
Figure 14. Linear relationship between water-saturated pH and soluble sulphate (r= -0.61) measured in cover soil of rehabilitated discard dump (pH = 7.0407 - .0017 * SO₄).

Table 9. Multiple regression results between soil pH and external independent variables.

	Beta	Std. Err.	B	Std. Err.	t(18)	p-level		Value
Intercept			4.705	0.633	7.432	0.000	Multiple R	0.678
CaNO₃	0.479	0.180	0.003	0.001	2.660	0.016	Multiple R²	0.460
Coal pH	0.316	0.177	0.172	0.096	1.786	0.091	Adjusted R²	0.370
Fs	0.254	0.182	0.038	0.027	1.392	0.181	F(3,18)	5.105
							p	0.010

Fs: Feldspar

Table 10. **Multiple regression results between log transformed electrical conductivity and external independent variables.**

	Beta	Std. Err.	B	Std. Err.	t(15)	p-level		Value
Intercept			2.029	1.389	1.461	0.165	Multiple R	0.801
Lime	1.280	0.358	0.000	0.000	3.581	0.003	Multiple R²	0.642
St	-0.634	0.192	-0.079	0.024	-3.301	0.005	Adjusted R²	0.498
Kt	-0.438	0.209	-0.017	0.008	-2.091	0.054	F(6,15)	4.478
KNO₃	0.652	0.386	0.005	0.003	1.691	0.112	p	0.009
Ct	0.197	0.168	0.055	0.047	1.172	0.260		
Coal pH	0.293	0.275	0.173	0.162	1.069	0.302		

St: Smectite, Kt: Kaolinite, Ct: Calcite

3.4.4. Sulphate as an indicator of salinisation and pyrite oxidation.

The preceding results do indicate the importance of sulphate concentration in the cover soil since sulphate is the by-product of pyrite oxidation. Most of the soluble salts can also be directly linked to the sulphate concentration in the soil solution (Figure 12). Figure 15 present results from the 1:2 water extracted sulphate concentrations measured in natural undisturbed soils, surface samples of the cover soil and cover soil-coal contact zone samples. The background samples included samples from undisturbed soil adjacent to burrow pit areas. The assumption can be made that a significant increase in the sulphate concentration would indicate an increase in salinity in the cover soil.

A Mann Whitney U test among cover soil and control samples and a Kruskal Wallis test were performed to test whether any significant differences exist in comparison to background soil samples collected in the vicinity of the mine and near the burrow pit areas existed. Non-parametric tests were performed since the high variances among populations did not allow for a conventional ANOVA-comparison. The hypothesis was tested that a significant increase in soluble sulphate concentrations will indicate salinisation because no additions of sulphate in the form of fertilisers were made. It probably would have been better to compare the results for each dump but the analysis was performed to determine the overall change in the soluble sulphate.

A significantly higher soluble-sulphate concentration was found in the cover-soil surface as well as soil-coal contact zone in comparison with background natural and semi-natural soils (Figure 15). The sulphate concentrations within the cover soil also

differed significantly among dumps. The average sulphate concentration in the surface of the cover soil on all dumps varied between 454.458- 30.51 mg.dm^{-3}. The increase in sulphate from the cover soil to the soil contact also differed considerably among dumps. At the dump in the Witbank vicinity the average sulphate only doubled from 34.44 to 68.57 mg.dm^{-3} whereas on a dump further east the increase between the cover-soil surface to the soil-coal contact was 61 times.

SO$_4$: KW-H(2,88) = 44.3641267, p = 0.0000; F(2,85) = 13.2411649, p = 0.000010
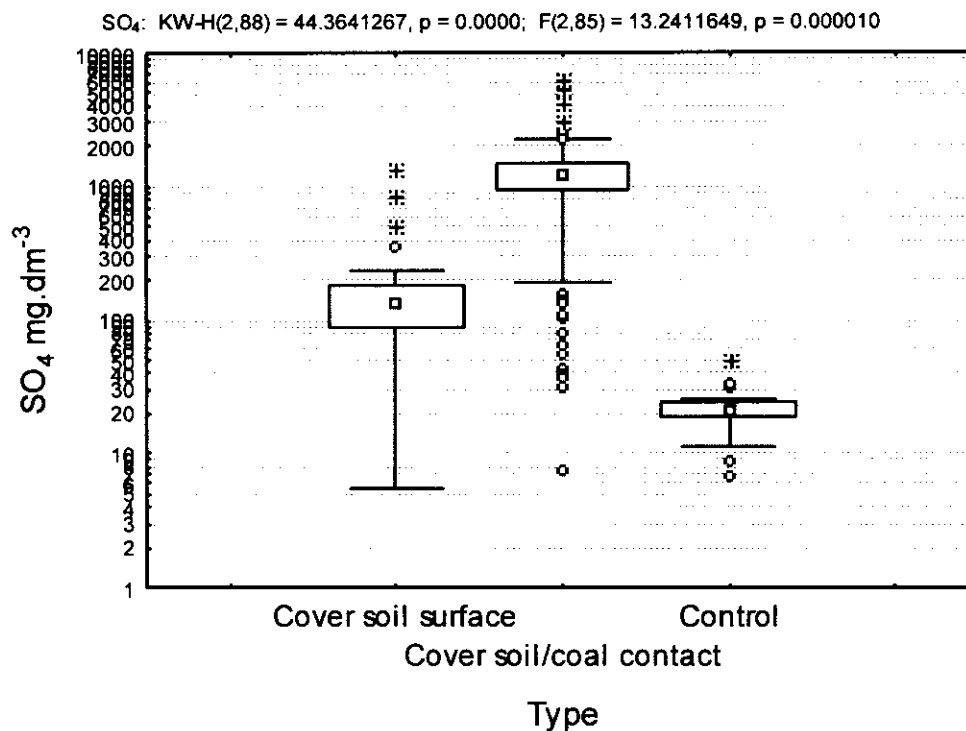
Figure 15. Comparison of cover-soil sulphate (logarithmic scale) at the surface and coal contact zone in comparison with natural soil samples at seven rehabilitated discard dumps. Box and whisker plots indicate mean, standard error deviation from mean, non-outlier range as well as outlier and extreme values.

3.4.5. Potential acidity

The potential acidity of the cover soil surface and subsoil was measured and compared with background soil samples (Figure 16). A Kruskal Wallis ANOVA also indicated that the effect of topsoil depth was significant. The average potential acidity of the cover soil surface was similar to background samples (potential acidity ≈0.2 cmol$_c$.kg^{-1} KCl). The average potential acidity of the cover soil contact zone with the discard coal layer

was considerably higher (potential acidity $=2.03$ $cmol_c.kg^{-1}$ KCl) in comparison with the average values measured for the background soil samples (potential acidity $= 0.17$ $cmol_c.kg^{-1}$ KCl). Figure 16 indicates a high potential acidity in the cover-soil contact zone with the coal (six samples with potential acidity values higher than 5 $cmol_c.kg^{-1}$ KCl).

Potenti al acidity: KW-H(2,76) = 7.83950123, p = 0.0198
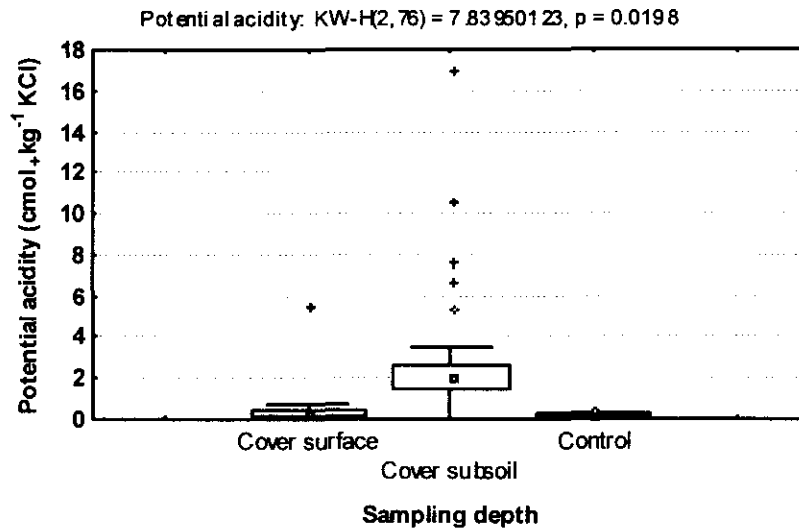
Figure 16. Comparison of cover-soil potential acidity at the surface and coal contact zone in comparison to natural soil samples (control) at seven rehabilitated discard dumps. Box and whisker plots indicate mean, standard error deviation from mean, non-outlier range as well as outlier and extreme values.

3.5.   Conclusion

Although the pH and EC-values measured over the four-year period for the surface layer of the cover soil indicate little salinisation or acidification it does not characterise the state in the subsoil of the cover layer. Results indicate that acidification and salinisation in the subsoil of cover soil were observed at certain dumps. The degradation of topsoil was closely linked to the acid formation of the coal discard. The occurrence of salinisation was strongly correlated to higher sulphate concentrations in the cover soil. In both regression models coal discard pH were included in the models to explain cover soil pH and salinity. Acidity could be linked to the higher potential acidity and the requirement for continuous lime application. Over application of lime is cautioned since regression results indicated that higher electrical conductivity values

could be contributed to lime applications. The salinity problem is currently not severe since electrical conductivity values on the surface are within the bound for effective growth of plants moderately sensitive to salt. The occurrence of elevated electrical conductivity (EC> 200 $mS.m^{-1}$) in the subsoil is, however, problematic as it could limit the effective root zone especially on dumps with a limited cover soil layer. The present fertilisation treatments were effective to neutralise the acidity on the surface. Doronila and Fox (1990) found that bare patches on rehabilitated coal dumps were frequently associated with a significantly higher electrical conductivity (EC 500 mSm^{-1}) and acidity (pH 4.7) in comparison to non degraded pastures where the salinity was approximately 300 $mS.m^{-1}$ and pH 5.6. The sensitivity of grass species to adverse saline and acidic conditions must be carefully evaluated. Brauer and Wolfson (1986) showed that *Digitaria eriantha* could grow under high saline conditions although *Chloris gayana* was more successful. *Digitaria eriantha* increased in production under saline conditions with the additions of high NO_3-N applications (200 $mg.dm^{-3}$ NO_3-N) (Brauer & Wolfson, 1986).

The occurrence of acidification of the cover-soil, especially deeper subsoil, was closely linked to the current acidity of the underling coal discard. The effectiveness of fertiliser treatments on the subsoil seems to be limited. The importance of monitoring the acidity in the coal at intervals is illustrated by Backes *et al.* (1986) and is also advocated by Loos *et al.* (2000). Under normal oxidation processes the formation of acid material, mainly in the form of sulphur acid is governed by available oxygen and is relatively slow. By attempting to maintain the pH above 4 the rate of oxidation can be controlled but if the discard material acidifies below a pH of 4 a further reaction catalysed by *Thiobacillus ferrooxidans* kicks in and this process has a 10^6 higher oxidation rate (Backes *et al.*, 1986) and can occur under anaerobic conditions. Rehabilitated dumps with cover soil in contact with acidic spoils (pH <4) will be severely effected not only regarding its pH but also salinity since large quantities of acids and sulphates may be released. The thickness of the topsoil will probably determine to what extent vegetation is effected. A cover-soil layer less than 300mm will probably not be able to buffer the effect on acid coal discard and the vegetation on such soil covers will not able to sustain a closed cover over the long term.

In this study sodicity was an infrequent problem and most salt will presumably precipitate as gypsum and magnesium sulphates. Because cover soil surface pH is fairly neutral it must be presumed that the fertilisers applied and lime were successful

to maintain a neutral cover-soil layer surface. The question is will this trend be sustained if the cover soil is not further fertilised and maintained? On dumps where results did not indicate that coal pH is a potential problem, to what extent will the cover soil acidify? It must be kept in mind that acidification is a natural process and is more likely to occur in sandy less-buffered soils with a low organic matter and colloid content (Mengel and Kirby, 1986).

The effect of the coal discard on the topsoil surface acidity and salinity is not directly visible in the surface layer (100-150mm) of the cover soil. An increase in sulphate concentration in the cover soil surface, however, suggests capillary movement of sulphate salts and acids to the surface. The increase in the soluble sulphate concentrations is currently not high enough to be concerning and the electrical conductivity on most dumps was manageable. The result indicated that at the current base saturation and neutral pH levels the potential for acidification over the short term is also limited on most dumps. This is probably largely due to continuous application of lime and the exclusive use of nitrate-based fertilisers. The low cation exchange capacity and clay content of the sandy cover soils, at three of the dumps, makes these dumps vulnerable for acidification since the cover soil on these dumps will be characterised by a low buffer capacity. .

The study concluded that high salinity is a consistent potential problem at deeper subsoil layers on rehabilitated discard dumps. Acidity is site specific and will depend on the current rate of pyrite oxidation and the buffer capacity of the cover soil. The current acidity and modelling of the potential acidity in a dump could be good indicators of success. The physical and chemical properties of the cover soil must be considered in conjunction with the present and potential acidity levels of the cover and underlying coal discard for evaluation for mine closure.

4. DISCUSSION AND CONCLUSION

4.1.   Assessment of topsoil quality based on indicator values

In Chapter 1 performance guidelines for pH and salinity were determined based available literature. For each of the two parameters an optimum range, and critical range or value were stipulated. A pH of 6.5 with a deviation of 0.5 to both ends, and an electrical conductivity range less than 200 $mS.m^{-1}$ were stipulated as optimum values. A pH between 5.5 to 7.5 was stipulated as the critical range. The critical electrical conductivity value for salinity was set at 400 $mS.m^{-1}$. The guideline values for pH was determined based on the probability of heavy metal toxicity as well as nutrient availability especially phosphorus. The guidelines for salinity considered the probability of salt damage due to the disruption of osmotic balance between roots and the soil solution as well as the sensitivity of grasses, in general, for saline conditions.

The average pH and electrical conductivity measurements of the cover soil surface, determined at the different dumps for the period 2000-2003, were compared with the guidelines for pH and electrical conductivity (Table 11).   The dumps at Newcastle and Witbank deviated below the performance pH value of 6.0. The Newcastle dump was the only site where the average cover soil pH deviated below the critical pH of 5.5 (2001 survey). The standard deviation of the pH (H_2O) was higher than 0.5 at these two dumps, increasing the probability that acidification is occurring.   The average cover soil pH on the Witbank dumps was below 6.0 in 2001 and the average cover soil pH on the Newcastle dump deviated below the critical pH of 6 during 2001 and 2002. The cover soil pH on the dumps near Bethal and Breyton deviated above the critical pH of 7.5.

The average electrical conductivity for all surface samples was below the performance value and therefore the current risk for salinisation remains low (Table 11). At present the highest risk area was the dump near Newcastle. The high standard deviation of the electrical conductivity is a concern at the Newcastle dump and indicates the potential occurrence of high salinity values at some localities on the dump or insufficient sampling.

Similar assessments for pH and electrical conductivity were conducted for the subsoil samples collected in 2002-2003 based on the success criteria stipulated in Chapter

1. Based on the comparison the dumps were ranked according to their compliance to the criteria (Table 12).

Table 11.   Comparison of average cover soil surface pH and electrical conductivity measurements, measured during 2000-2003 on the rehabilitated discard dumps, with performance standards indicated in Chapter 1.

			pH (H₂O) (PC= 6.5±0.5)				EC (mS.m⁻¹) PC<200			
		N	Mean	Std dev	CV		Mean	Std dev	CV	
All Groups		180	6.71	0.99	14.74	1.03	78.90	86.52	109.65	0.39
Bethal	2002	12	7.75	0.42	5.43	1.19	50.33	28.32	56.27	0.25
Bethal	2003	13	7.57	0.44	5.85	1.16	62.38	36.73	58.88	0.31
Breyton	2000	4	7.13	0.59	8.26	1.10	43.25	28.59	66.11	0.22
Breyton	2001	4	7.32	0.19	2.65	1.13	49.25	16.15	32.80	0.25
Breyton	2002	6	7.30	0.48	6.54	1.12	46.33	20.21	43.61	0.23
Breyton	2003	6	7.62	0.13	1.70	1.17	54.17	16.09	29.71	0.27
Ermelo	2000	11	6.72	0.34	5.13	1.03	33.18	8.35	25.17	0.17
Ermelo	2001	11	6.65	0.62	9.33	1.02	36.09	49.62	137.50	0.18
Ermelo	2002	13	6.87	0.66	9.67	1.06	40.15	29.81	74.23	0.20
Ermelo	2003	14	7.20	0.32	4.51	1.11	71.71	69.28	96.61	0.36
Newcastle	2000	11	5.55	1.15	20.63	0.85	135.64	126.59	93.33	0.68
Newcastle	2001	11	5.11	0.91	17.71	0.79	166.64	150.19	90.13	0.83
Newcastle	2002	16	6.10	1.27	20.81	0.94	141.00	139.96	99.26	0.71
Newcastle	2003	14	6.57	0.85	12.93	1.01	152.71	94.45	61.85	0.76
Ogies	2000	2	6.73	0.97	14.41	1.03	100.50	33.23	33.07	0.50
Ogies	2001	2	6.84	0.49	7.14	1.05	34.00	15.56	45.75	0.17
Ogies	2002	4	6.96	0.54	7.69	1.07	36.25	11.62	32.04	0.18
Ogies	2003	4	6.87	0.36	5.24	1.06	86.75	47.05	54.23	0.43
Witbank	2000	5	6.36	0.68	10.76	0.98	41.20	13.26	32.17	0.21
Witbank	2001	5	5.79	0.54	9.27	0.89	35.00	8.54	24.41	0.18
Witbank	2002	6	6.70	0.86	12.92	1.03	22.50	8.31	36.95	0.11
Witbank	2003	6	6.88	0.71	10.30	1.06	88.33	21.36	24.18	0.44

The subsoil samples at the Breyton and Ogies dumps were on average the least acidic or saline and conformed to the standards set for pH and electrical conductivity. The subsoil pH reflects the coal samples average pH of 6.1 ±0.32 and 6.72 ±1.52 for Breyton and Ogies (Table 12). The subsoil samples collected at the three larger damps (dumps situated near Ermelo, Newcastle and Bethal) did not conform to the pH standard. The subsoil on the dumps near Newcastle and Ermelo also had high

average electrical conductivity values. The coal samples pH measured at Newcastle and Ermelo were respectively 5.10 ±1.76 and 4.34 ±0.28.

The pH and electrical conductivity values for the subsoil of Ermelo and Bethal are less critical considering the cover soils are on average 500mm thick, but needs to be monitored. The pH and electrical conductivity of the subsoil on Newcastle dump are more critical due to the shallower cover soil depth (less than 300mm thick) increasing the risk of possible influence on vegetation growth.

Table 12. A comparison of subsoil pH and salinity measurements, measured during 2002-2003, on the rehabilitated discard dumps with performance standards indicated in Chapter 1.

Study area	rank	N	Mean	pH(H$_2$O) Std dev	CV		Electrical conductivity (mS.m^{-1}) Mean	Sdt dev	CV	
Newcastle	6	15	**4.64**	1.24	26.76	0.714	**232.733**	178.443	76.673	1.164
Ermelo	5	13	**5.20**	1.02	19.70	0.800	**209.308**	136.414	65.174	1.047
Bethal	4	7	**5.36**	1.350	25.21	0.824	175.000	113.6779	64.959	0.875
Witbank	3	6	**5.37**	0.64	11.88	0.825	32.333	14.320	44.289	0.162
Ogies	2	7	6.94	0.75	10.84	1.068	154.714	147.365	95.250	0.774
Breyton	1	9	6.60	0.66	10.05	1.016	65.778	55.863	84.927	0.329

4.2. Assessment of analysis methods used

A variety of methods are available to conduct soil chemical analyses. Chapter 2 gave a description of the soil chemical analyses methods used in this study. This section compares methods described in chapter 2 with what is presently preferred or recommended for the monitoring of mine site (Sandoval & Power, 1977, Berg, 1978, Askenasy & Severson, 1980, Chamber of Mines, 1981 and Wyoming Department of Environmental Quality. 1994).

The current methods used in this study comply with these methods with regard to the extraction of macro-elements with ammonium acetate (NH$_4$Oac) and the determination of cation exchange capacity using NH$_4$Oac as described by the American Society of Agronomy (Black, 1965 and Thomas, 1982). The methods used to determine pH and electrical conductivity are universal. Organic matter was determined following the Walkley-Black method, which is also the preferred method

for organic carbon determination. Literature, however, cautioned against the use of the Walkley-Black method since it is not sensitive against contamination from coal residues (Sandoval & Power, 1977). An alternative method for determining organic carbon is by dry combustion using a Leco C determinator as used by Schoenholtz *et al.* (1992). Phosphorus was determined in this study with the Bray-1 extractant, which is a standard method frequently used and referred to in rehabilitation guidelines. Olsens & Sommers (1982), however, advise against the use of the Bray-1 method where free carbonate is present in the soil, as it can influence the result from the Bray-1 by neutralising the extractant (HCl with NH_4F). The precipitation of CaF_2 is also a potential problem that could influence the accuracy of the analysis. An alternative method is the $NaHCO_3$ extraction method (Olsens method), which is more effective for measuring extractable phosphorus in neutral to calcareous soils (Berg, 1978). Since the cover-soil was mostly acidic to neutral the Bray–1 method is the best method to use and would reflect the fertility of the soil in terms of plant production. Berg (1978) reported that grass growth response was significantly correlated to Bray-1 extracted phosphorus in Pennsylvanian coalmine soils. Boron was determined in this study with an azomethine-H method described by Barrett (1978). The method was used, as it is a quicker method when compared to the hot water extraction method. The results from the analysis was, however, highly variable with high variability over sampling years on similar sampling locations. This is probably due to the low boron values measured in the cover soil (0.084 ± 0.19 mg.dm^{-3} in 180 samples). The method recommended for determining boron is with a hot water extraction with $BaCl_2$. Schafer (1979) published regulatory guidelines specifically for mine soil based on the hot water extractable method. A 1:2 water extraction procedure was alternatively followed in this study to determine the concentration of soluble macro-elements (Ca, Mg, K, Na), anions (PO_3, SO_3, NO_3 and Cl) as well as micro-elements (Fe, Cu, Zn and Mn). Water extraction to determine phosphate yielded low concentrations. In this study macro-elements determined with NH_4Oac method was better related to fertiliser inputs than water extractable macro-elements (see chapter 2). The results therefore indicate that the NH_4Oac method represented the fertiliser inputs better and must preferably be used to assess the availability and ratio between calcium, magnesium and potassium. A variety of water extraction methods with varying amounts of water are used from saturated paste, 1:1, 1:2 or 1:5. More extreme extracting methods are available to determine micro-element concentrations, varying from extractions in acid mediums, in salt solutions or EDTA. Cummings and Elliott (1991) reported toxicity levels for

heavy metals that were determined from EDTA, water-soluble extract, or saturated extracts. Mengel and Kirby (1987) reported good correlations between zinc contents in leaves and DTPA extracted zinc in soils. De and Mitra, (2002) used a nitric acid digestion method to determine heavy metal concentrations in coal open-cast areas in India. The available nitrogen (nitrate and ammonium) in the cover-soil samples was assessed in this study with a 1:2 water extract. Soluble nitrate was quantified with ion chromatograph and ammonium with an ammonium-selective electrode. From literature available the preferred methods used to determine mineralised ammonium and nitrate are with a KCl solution extraction method. Total nitrogen is frequently reported and indicated as a success criterion. Total nitrogen is also used to calculate the C/N ration. De and Mitra (2002) conducted an alkaline permanganate method to determine total nitrogen. A more frequent method used for the determination of total nitrogen is the Kjeldahl digestion method. Schoenholtz *et al.* (1992) determined the available nitrogen by following an anaerobically mineralised NH_4^+-N method as described by Keeney (1982). Lime requirement for coal before rehabilitation and of the cover soil was based on a double buffer method. Although this method is suitable for determining the lime requirement for the cover soil it is not the best method for determining the lime requirement of coal containing FeS_2 (pyrite).

4.3.   Assessment of amelioration methods used

A broad spectrum of ameliorants and fertilisers are available to improve the growth medium or cover soil for rehabilitating discard dumps. Fertilisers used in the study were based on soil analyses and are described in chapter 2 of the study. Chapter 2 indicates the influence of the fertilisation programme on the fertility of the cover soil surface. Nitrogen was added in the form of nitrate (KNO_3, $CaNO_3$ or $MgNO_3$). The use of sulphate-based fertilisers such as gypsum was also refrained from since the sulphate concentration is already potentially high as indicated in preceding chapters.

The preferred use of nitrate fertilisers on coal-rehabilitated areas is not prominent in available literature dealing with fertilisation of coal-mined land. Results from the study, however, indicate a relation between phosphate availability and the application of nitrate fertilisers but also between phosphorus availability and the application of lime. The preference for nitrate base fertilisers has some trade-offs that must be noted and literature gives contradictory conclusions. The acidification effect of ammonium fertilisers is well illustrated in literature, especially the application of

ammonium sulphate and urea (Havlin et al., 1999). The effect of an exclusive application of nitrate fertilisers to sustain a neutral pH is discussed by Havlin et al. (1999). In general plants do assimilate nitrate more readily although both forms (NO_3 and NH_4^+) are taken up (Mengel and Kirby, 1987). Nitrate will promote plant growth as long as other nutrients are sufficient (Heuer, 1991 and Kotsiras et al., 2002). An excessive ammonium concentration in the soil solution has been found to be toxic to plants but is lesser so in acid soils since hydrogen concentrations depresses ammonium formation. Lasa et al. (2001) reported a reduction in growth with ammonium assimilation but also resulted in an increase of organic nitrogen (protein) within plant biomass. The sensitivity of plants to ammonium is variable and plants assimilating ammonium in roots are less sensitive to ammonium toxicity (Lasa et al., 2001). A study on cucumber by Kotsiras et al. (2002) has found that the type of nitrogen has a significant effect on the uptake and allocation of nutrients in reproductive material.

Brauer and Wolfson (1986) reported that both Chloris gayana and Digitaria eriantha have a preference for nitrate-based fertilisers under saline conditions. The results of Brauer and Wolfson (1986) contradict those of Rethman (1987) who found better production results with the application of nitrogen in the form of lime ammonium nitrate (LAN) and ammonium sulphate. Rethman (1987) proposes also a split application of fertilisers based on rainfall patterns. Although Rethman (1987) recommends a fertiliser level of 300-400 kg.ha^{-1} under high fertility levels, more recent research with Digitaria eriantha indicates maximum yields with nitrogen applications of 80 kg.ha^{-1} on soils with a clay content of 20% and phosphorus and potassium levels of 8 and 56 mg.kg^{-1} respectively (Pieterse & Rethman, 1995). The pH (H_2O) of the soil was 5.9 and therefore relatively acidic. Palmer et al. (1986) investigated the effect of type and application rate of nitrogen on biomass production on colliery spoil material. At relatively large applications of nitrogen Palmer et al. (1986) recorded higher yields when nitrogen was supplied as ammonium sulphate in comparison with calcium nitrate although the effect was not significant during later harvests. The study further could not find any difference in the decline in nitrogen levels between plots treated with nitrate or ammonium and therefore leaching of nitrate was not more or less prominent to ammonium in these trials. Palmer et al. (1986) did not report difference of phosphate availability with the application of different forms of nitrogen (calcium nitrate vs. ammonium sulphate) on colliery spoils. Phosphate level had a consistent positive effect on biomass production especially on

plots where higher nitrogen fixation by white clover was observed (Palmer *et al.*, 1986). Palmer *et al.* (1986) further indicates that nitrogen fixation by legumes had an acidification effect to the same extent than with the application of ammonium sulphate. A local study of Ströhmenger *et al.* (1999) investigated the role of fertilisation to alleviate sulphate salinity on wheat, irrigated with sulphate-dominated saline water. Ströhmenger *et al.* (1999) recommended the combined application of ammonium and nitrate to a ratio of 2:1 and 1:1 since high sulphate concentrations where found to suppress nitrate uptake.

Literature indicates that nitrate is a preferred source to limit further acidification of the root zone due to uptake of ammonium by roots and the nitrification of ammonium to nitrate. The potential exists that free ammonium will be oxidises (through the process of nitrification) to nitrite and nitrate if not assimilated by roots or adsorbed on exchange complexes (Venter, 2003 and Singer & Munns, 1992). The result is a release of hydrogen ions in the system. The free hydrogen ions will be neutralised as long as plants assimilate all nitrates. Acidification will only result if the plant directly takes up ammonium or a net loss of nitrate due to leaching occurs. The long-term nutrient cycling will, however, depend on the availability of exchangeable and adsorbed nitrogen in the forms of ammonium or organic nitrogen since mineralised nitrate is quickly leached if not taken up. Mengel and Kirby (1987) concluded that it is probably better to apply nitrogen in both forms. The amount (application of small amounts at more regular intervals) and time (during the period of maximum uptake and growth) of applying fertilisers can also mitigate the problem of nitrification of excess ammonium. Speculation also exist that ammonium is the more available form of nitrogen in climax and late serial ecosystems in comparison to pioneer systems where nitrate concentrations dominates. This tendency was confirmed by studies of Wali (1999) who found a decrease in available nitrate and an increase in ammonium nitrogen with increase rehabilitation age. The financial implication of only applying nitrate is, however, considerable if the price of nitrate fertilisers is contemplated (Table 13). The use of only nitrate must be justifiable against the current acidity of the cover soil, the sensitivity of grass swards against acidity, the buffer capacity of the medium and the benefit of the long-term economic potential of the rehabilitated land use or the financial implication of only applying nitrate instead of both forms such as lime ammonium nitrate. To date the mine has accepted that it is justifiable to only use nitrate fertilisers to ensure best practice although it is not commonly done so in the industry.

Current inputs of nitrate sustained the soluble nitrate in the soil but did not increase the available nitrogen. Unfortunately total nitrogen was not measured as part of the analyses therefore not much can be concluded about the nitrogen dynamics in the soil. Water extracted nitrate cannot be regarded as a good estimator of nitrogen in the soil since it is highly soluble and is quickly taken up or leached from the root zone. A sufficient input of nitrogen in the soil must be considered important to sustain productivity. Current applications of nitrogen is lower than that recommended to improve productivity. The stimulation of biomass through fertilisation and defoliation is regarded important to increase root development and therefore organic matter input on rehabilitated land. The role of nitrogen application has been dealt with earlier. Todd *et al.* (2000) illustrated the role of litter cover as nitrogen sinks on rehabilitated by determining a significant correlation between nitrate and litter cover. The inclusion of legumes is a solution to ensure long-term availability of nitrogen. As already noted the choice of leguminous species must be carefully considered if the dumps are to be grazed by cattle since bloat is a potential problem. Lucerne is also sensitive to acidic conditions. In general Lucerne has been used for rehabilitation in the past. Subjective observations on a rehabilitated coal ash dam in the Kriel area suggested that rehabilitated areas with Lucerne were in a comparable better condition than those areas without Lucerne. Lucerne also grows on the dump near Breyton, which is at present the dump with the highest soluble nitrogen and a crown cover of 80% (Morgenthal & Van Rensburg, in press). Very little research results from trials with legume species have been conducted, although South Africa has a variety of indigenous legume species available. The importance of a successful rehabilitation design and effective vegetation cover to reduce runoff, erosion and improve water quality was illustrated by Carrol *et al.* (2000) and Evans (2000) on Australian mine sites.

Considerable attention was given to the application of kraal manure on the rehabilitated discard dumps to increase the organic content, to increase the exchange capacity of the soil, to add additional nutrients and to stimulate microbiological activity within the cover-soil (Charman & Roper, 1991). The use of organic waste and other forms of sludge have attracted considerable research. Sydnor and Redente (2002) investigated the beneficial use of applying bio-solids and mushroom compost to acid mine waste and reported increased vegetation productivity with application of organic waste. The effects of sewage sludge, lime and gypsum on the composition of percolate from acidic coal refuse material were

studied by Pietz *et al.* (1989). The sludge used by Pietz *et al.* (1989) was effective to reduce total acidity of 0.018 cmol$_c$kg^{-1} for each ton sludge applied and reported that a combined sewage sludge-lime treatment was the most effective treatment to maintain percolate water pH and to reducing sulphate percolation Pietz *et al.* (1989).

Pichtel *et al.* (1994) compared the ameliorating properties of sewage sludge, composted papermill sludge, power plant fly ash and limed topsoil on toxic mine spoils. Papermill and sewage sludge were equivalent to limed topsoil in providing nutrients. Application rates tested by Pichtel *et al.* (1994) varied between 67, 90 and 112 Mg.ha^{-1} papermill sludge and 224 Mg.ha^{-1} sewage sludge and 448 Mg.ha^{-1} fly ash. Seaker and Sopper (1984) evaluated the use of a single application of 11, 90 and 184 Mg.ha^{-1} dry sludge to spoil-banks and recommended that it is a successful method of establishing vegetation on opencast spoil material. In general sewage sludge experiments on mine soils have been shown to increase nitrogen and phosphorus availability, increase the pH and decrease aluminium concentrations (Olesen *et al.*, 1983). The indiscriminate application of sewage sludge and other forms of sludge are cautioned against. Research has indicated the addition of heavy metals as well as a higher availability of heavy metals after the application of sewage sludge and other forms of sludge (Olesen *et al.*, 1983). Brady and Weil (1999) give the following recommendations for maintaining and improving soil organic content:

a) Continuous supply of organic materials

b) Organic matter must be maintained in accordance to what the soil and climate dictates.

c) A linkage between soil nitrogen and organic matter exist and therefore adequate nitrogen supply is needed.

d) Maximum plant growth will increase the amount of organic matter by under and above ground residues.

Perennial vegetation should be encouraged and maintained.

Table 13. Cost analysis for different fertilisers and kraal manure (transportation and application cost excluded)

Fertiliser	%N %	Application Kg.ha^{-1}	Nitrogen applied by 200kg.ha^{-1} dressing Kg N.ha^{-1}	Cost R.ton^{-1}	Cost efficiency R.kg N^{-1}	Product needed to apply 60kg N.ha^{-1} Kg.ha^{-1}	Acidity Potential [a] CaCO$_3$kg.kg fertiliser^{-1}
LAN	28.00[#]	200	56.00	1740	31.07	214	0.57
Ca(NO$_3$)$_2$*	17.07	200	34.15	2484	72.75	351	
KNO$_3$*	13.00	200	26.00	3907	150.27	462	
Mg(NO$_3$)$_2$*	18.92	200	37.84	2683	70.91	317	
Kraal manure	0.80[$]	200	1.60	50	31.25	7500	
Urea	46.00[#]	200	92	2480	26.96	130	1.64

*Pure product

as indicated by Kynoch

$ Determined from chemical analysis on manure applied to study area in 2002 (Appendix A)

[a] Venter, 2003

The application of large quantities of organic material to large surfaces is, however, not regarded as financially feasible because it is to expensive, has a variable nutrient status and is not easy to apply over large surfaces (EPA, 1995 and National Research Council, 1993). The benefits associated with applying organic wastes, such as manure, is far more beneficial than as a nutrient supplement but also has other soil chemical and soil physical benefits (National Research Council, 1993) making it a justified action. The current source of organic material is relatively cheap (Table 13) although the transport and spreading of organic material is cumbersome due its bulk volume.

4.4. Management strategies and recommendations

This study deals primarily with coal discard as an environmental aspect during a post commissioning or mine closure phase. As indicated in chapter 1 some of the major impacts associated with coal discard are amongst others acid mine drainage, ground water pollution and the aesthetic impact on the landscape form and loss of agricultural potential. The general management strategy is to mitigate these impacts by compacting the discard, cover it with a cover soil layer and revegetating it with a grass seed mixture. Due to the ecological sensitivity of opencast mine it can, at best, be regarded as low potential grazing land but is preferably "used" as wilderness land. By rehabilitating the coal discard further "impacts" are generated on the ecological system now covering the discard. The process of rehabilitating the discard becomes an environmental aspect in it self that must be managed. This study specifically deals with the aspect of mine rehabilitation and activities aimed at mitigating the impacts of the coal discard on the rehabilitated ecosystem.

The following impact of the coal discard on the rehabilitated ecosystem could be identified with the information available:

4.4.1. Acidification and salinity of subsoil

A major concern is the further acidification of the coal contact after placement of a cover soil layer and its potential long-term impact on sustainability of the established vegetation as well as the potential for acid leaching at the periphery of the dump. The effective control of pyrite oxidation and acidification must therefore be correctly managed. This is achieved by ensuring that the acidification potential is correctly

determined using the most appropriate method, that the best available technology is selected, considering the long-term risks, the achievement of mine closure and financial costs. Three aspects must be considered during rehabilitation namely the effective compaction of the coal discard, sufficient application of lime to the coal discard, the use of alternative technologies to limit aeration and water infiltration to the coal contact. The initial lime application to the coal discard must be sufficient to neutralise the current acids as well as some of the potential acids. The lime requirement of the coal discard was base on a double buffer method that is mostly suitable for agricultural applications. The double buffer method mostly measures the exchangeable acidity and does not consider the total effect of pyrite oxidation in the medium. The determination of soluble sulphates will also not solve this problem since this only accounts for the already neutralised fraction or those present as sulphuric acids.

Morgenthal *et al.* (2003) indicated the possibility of acid leaching at the periphery of dumps with a high acidity forming potential. The result is highly acidic and saline conditions along a narrow region at the bottom of the dumps. The danger therefore exists that although the upper slopes and top have stabilised the potential for degradation on the periphery of the dump remains high. Areas of higher acidity or salinity were evident by the precipitation of gypsum salts or vegetation moribuncy and dieback during winter months. Areas of considerable leaching were also characterised by the occurrence of *Phragmites australis.* These conditions can therefore be used to indicate degradation. A further indicator of coal discard exposure is the occurrence high percentage of weeds, which was observed at one of the other sites.

4.4.1.1.   Objective:

4.4.1.1.1.   To accurately assess the potential of acidification of the coal discard as a result of pyrite oxidation to ensure an accurate risk assessment.

4.4.1.1.2.   To implement the best corrective rehabilitation technology to mitigate the effect of continual pyrite oxidation, to limit acid mine drainage and to ensure a more long term self sustaining vegetation cover.

4.4.1.2.   Proposed environmental management strategy

The proposed environmental management strategy is first to quantify the pyrite content using an excepted method to determine the equivalent lime needed to neutralise the pyrite of the first 30cm. The data must be used to assess the risk for acidification and to guide liming of the surface coal layer. Secondly to decide if more cost intensive methods are needed to limit oxidation of the coal residues such as the application of compacted clay layers and what cover soil depth will be required to ensure a buffer between the effective root zone and coal contact zone. The standard method currently used is to apply a dressing of lime and grade the lime into the surface of the coal discard, compact the coal and to cover the coal discard with a 500mm soil.

The Wyoming Department of Environmental Quality proposes the use of the method as stipulated by Smith *et al.* (1974), which is actually an adapted method from Jackson (1958) to determine acid-neutralising capacity. The method recommended by the Wyoming Department of Environmental Quality determines the acid – neutralising capacity of the sample expresses as a percentage of $CaCO_3$. Potential methods that can be used to determine the pyrite content is that given by the British Standard Institute (1977) specifically developed to quantify the pyrite in coal. Costigan *et al.* (1981) used a method derived from Dacey and Colbourn (1979). Askenasy and Severson (1980) propose the method of Sobek *et al.* (1978), which is a method recommended by the USA EPA.

The study of Loos *et al.* (2000) gives recommendations for limiting the oxidation of pyrite and limit acidification of the cover-soil.

a)   The use of suitable clay layers to minimise gas exchange

b)   The use of capillary break layers

c)   The use of an appropriate thickness of cover soil.

d)   The establishment of an effective vegetation cover to extract water away from the coal discard and to limit erosion.

Other rehabilitation strategies that are currently followed are:

a)   The compaction of coal discard, to limit oxidation and water infiltration into the cover soil.

b)   The application of lime according to the potential acid formation of the coal discard.

c)   The placement of a cover soil layer of 500mm thick. Any available soils are used.

The placement of combusted coal residues (coal ash) over uncombusted material (if available) to serve as capillary break layer, to place a neutral/alkaline buffer layer between coal and cover soil and to limit further aeration and water infiltration to uncombusted coal discard can also be considered.

The rehabilitation techniques indicated above are expensive and therefore it is financially imperative to select the correct rehabilitation method based on an accurate assessment of risks involved. The application of the most appropriate rehabilitation technology is fundamental since it would determine the level of maintenance and potential for mine closure in the future.

4.4.1.3.   Checking and corrective action

The periodic sampling of the coal discard to assess the occurrence of acidification of the coal discard can give information on the long-term sustainability of the rehabilitated discard dump. It is recommended that the current acidity of the subsoil and coal be measured with a pH sensitive electrode using a saturated water extract and/ or KCl extract. Electrical conductivity must be measured using a saturated paste extract with a standard electrical conductivity meter. Although resistance can also be use to determine salinity of a soil, most results and guidelines specify salinity guidelines based on electrical conductivity measurements. The existing soil sampling points for the assessment of soil nutrient status can be used to monitor subsoil. To assess the potential occurrence of acidity the surface, subsoil and the coal discard must be sampled with the similar sampling procedure used in this study. The concentration of sulphate salts can be measured to corroborate the salinity of the cover-soil since salinity was directly related to the concentration of sulphate (see chapter 3). The current method can be used to determine the water-soluble sulphate concentration. Care must be taken not to contaminate the subsoil sample with coal residues when sampling the subsoil since this could give misleading results. An increase in the salinity and acidity over consecutive sampling periods will indicate that pyrite oxidation and acid formation are taking place in the spoil material. As indicated from literature a pH of 4.5 or lower is critical as this is the level of acidity where rapid oxidation takes place leading to large quantities of acid release. This is because a cyclic system is created in which ferrous ions released from oxidised pyrite are further oxidised bacterially to ferric ions, which then acts as an oxidising

agent on pyrite, generating more ferrous ions. It will probably be advisable to monitor the subsoil acidity at the onset of rehabilitation, periodically after rehabilitation and annually few years leading up to mine closure.

The only corrective action after rehabilitation is by liming the surface soil to maintain the neutrality of the growth potential at the surface. Although a sand medium will increase gas exchange and water infiltration the effective depth of liming will also be deeper. To sustain a fertile growth medium, thereby maintaining the productivity of the medium, could also help mitigating the effect of acidification of the subsoil. Probably the most extreme form of amelioration is to apply a compacted clay layer and reapply a cover soil layer over the failing system and to revegetate the dump again.

4.4.2. The sustaining of a productive ecosystem

During discussions with soil scientist and environmental managers involved with opencast mine rehabilitation, it becomes apart that the current management strategy is to sustain a high level of fertility during the initial period of rehabilitation when vegetation is in an developing phase and thereafter slowly decrease the application of ameliorants. A high fertiliser input is also sustained since defoliation practices will require higher inputs. By reducing the fertiliser applications it are hoped that later successional grass species, normally growing in less fertile environments, will colonise. The successional pathways of vegetation on rehabilitated land are not well studied, especially over the longer-term. Morgenthal (2000) observed that vegetation on alkaline coal ash developed into a *Hyparrhenia hirta* (Common Thatching grass) dominated vegetation, if *Hyparrhenia hirta* is present in the grass sward. It can therefore be speculated that under the correct conditions rehabilitated land would follow a successional pathway typical of old lands. This tendency was already visible on some of the slopes of the older rehabilitated discard dumps.

Probably one of the major reasons for the deterioration of rehabilitated land is because it is an artificial system of which the cover-soils structure and biotic components have been destroyed or disturbed. Rehabilitated land is therefore characterised by properties comparable to pioneer ecosystems such as soils with a weak structure, insufficient nutrients, a poor nutrient cycle and a low organic content. The impact of the rehabilitation process (type of seedbed preparation, fertilisation

and maintenance after seeding) on the long-term sustainability of the system is also important to consider.

4.4.2.1.   Objective

It is the objective of the management strategy to:

4.4.2.1.1.   Set guidelines for the monitoring of soil fertility
4.4.2.1.2.   To give guidance on the use of fertilisers and ameliorants

4.4.2.2.   Proposed environmental management strategy

Fertiliser's needs to be applied based on soil analysis of the cover soil before rehabilitation. The aim of fertilisation of the cover-soil is to provide an acceptable growth medium for the germination and development of a closed vegetation cover of perennial grass species, to apply fertilisers in such a manner to minimise loss of nutrients and to initiate the recycling of nutrients. Macro elements (Ca, Mg and K), nitrogen and phosphorus are the most important elements that needs to be added if insufficient or in the incorrect ratio. Calcitic or dolomitic lime is applied to neutralise current and potential acidity preferably to a pH of 6.5 and also ads calcium and magnesium to the system. Phosphate is added predominantly as super-phosphate although other forms such as rock phosphate can be used. Potassium is most frequently added in the form of NPK mixtures but can, as done on these sites, be added in the form of potassium nitrate. Although expensive to transport and apply, organic material such as kraal manure can be applied as additional source of nutrients, to improve the physical properties of the surface, adsorb excessive salts immobilize heavy metals such as aluminium and kick-start the soil microbiological component. The form and level of nitrogen must be carefully considered when selecting inorganic fertilisers: The following are important to note.

> a) An application rate of approximately 60 kg.ha^{-1} nitrogen is recommended to sustain productivity. The rate is for a low productive system with an approximate production level of 4 ton.ha^{-1}. An application in excess of 300 kg.ha^{-1} N has been recommended for high productive pastures.

b) Nitrate base fertilisers can be applied under extreme acidic conditions to prevent further acidification due to nitrification of ammonium and the uptake of ammonium ions by the root system.

c) The use of nitrate fertilisers is generally not considered financially justifiable. Nitrate based fertilisers are more often used in high productive agricultural systems where the expense are justifiable.

d) Applied nitrate is highly soluble and if not immediately assimilated by plant material it will be lost through leaching.

e) Ammonium will be the type of nitrogen available over the long-term, after maintenance has ceased, since it is preferentially adsorbed on the exchange complex.

To elevate compaction layers and improve the bulk density the cover soil must be prepared using the appropriate equipment. Mulch or organic material can be worked into the soil to improve the structure of the soil. This must be conducted prior to the revegetation since non-composted material can disrupted the C:N ratio within the soil and effect nitrogen availability

4.4.2.3.   Checking and corrective action

Soil fertility monitoring must be conducted, considering general theory and principles of monitoring such as ensuring it conforms to the land use objective, ensuring repeatability, ensuring representative sampling frequency and representative sampling locations. Geo-statistical techniques can be use to determine the spacing and number of samples to ensure representative sampling. An alternative is to place samples in a grid. Sampling location can also be based on variations in cover-soil properties, topography on the dump and considering known variation in the characteristics of the underlying coal discard. The numbers of samples will probability be a compromise between financial costs and ensuring representative sampling. Monitoring also explicitly implies a repetitive process and a programme must be developed with specific guidelines and success criteria for each area in mind. Considering the cost involved and the variability within soils an annual or twice annual monitoring interval is proposed. The time for sampling is probably a debate on its own but an appropriate time is before maintenance practices commence. Since maintenance is currently conducted during October-November, sampling

during August gives a good estimate of the condition before the growing season commences. Chapter 2 and 3 provide a description of the analysis methods used during the past three years. The annual vegetation audit programme of Mentis (1999b) also investigated the extractable phosphorus, potassium, zinc and acid saturation as well as soil organic content. Table 14 presents a list of recommended variables to be measured annually or periodically.

Soil physical properties have not been measured and are a weak point in the study. Previous studies by Nell and Steenekamp (1998) indicated that soil compactions and a high bulk density could be attributed for many of the problems associated with discard dumps. A study by Kellner and Morgenthal (2003) showed similar problems for rehabilitated ash disposal dumps rehabilitated in a similar fashion as discard dumps. In this study compaction was not a particular problem at the Witbank, Ogies and Breyton dumps since the soils have a sandy texture with a loose structure. Proper root penetration could be a problem at Ermelo, Bethal and Newcastle dumps. These dumps have a fine texture (high silt fraction) and therefore have the potential to compact. Burley et al. (1989) related plant productivity especially to soil physical parameters such as hydraulic conductivity and bulk density in a multiple regression model. In their model the ideal soil was a soil with a bulk density of 1.36 to 1.6 $g.cm^{-3}$ and a hydraulic conductivity of 3.3 to 101.6 $mm.h^{-1}$. Soil physical parameters are therefore critical for evaluating the fertility of cover soils and must be annually monitored as part of the vegetation audit or as part of the soil fertility monitoring, if necessary.

From experienced gained during this study and available literature, soil fertility success criteria for further monitoring and evaluating for mine closure are recommended in Table 14. According to Arshad and Martin (2002) soil quality indicators refers to measurable soil attributes that influence the capacity of the ecosystem to be productive (for crop production) and functional. Key indicators mentioned by Arshad and Martin (2002) is indicated in Table 14 with an asterisk. Leave analyses can also be periodically conducted since it gives an accurate state of the nutrient status and heavy metal concentrations within the grass sward.

The soil fertility-monitoring programme can be used to identify maintenance requirements. It is recommended that the fertilisation recommendations be made by an experienced soil scientist familiar with mine rehabilitation. Recommendations must also be in accordance to the end use and the rehabilitation strategy that is

being followed. Since the potential end use on coal discard will likely be wilderness land the fertilisation programme must ensure that the cover soil fertility is comparable to "semi-natural or improved grasslands" in terms of organic content, total nitrogen, phosphorus availability, salinity, acidity and bulk density after completion of the fertilisation programme.

Table 14. Key performance indicators recommended for measuring rehabilitation success. Asterisk indicates key soil indicators recommended by Arshad and Martin (2002).

It is recommended that guidelines according to the Wyoming Department of environmental quality (1994) be used or similar to the guidelines to select suitable burrow pits for cover soil.

Parameter	Method	Comments
Topsoil depth	Measuring tape and augering	Measure during placement of the cover soil. Specification within the rehabilitation plan will therefore be success criteria
Slope steepness and length	Clinometer to estimate the slope	Slope length and angle will depend on the rehabilitation plan. Specification within the rehabilitation plan will therefore be success criteria
Rehabilitation design	Visual inspection if specifications were adhere to	Specification within the rehabilitation plan will therefore be success criteria
pH (cover soil coal discard)*	Saturated water extract and or KCl	Measure at cover soil surface, subsoil and coal contact
Salinity (cover soil/coal discard)*	Electrical conductivity	Measure at cover soil surface, subsoil and coal contact
Ca, Mg, K, Na*	Ammonium acetate Ca, Mg. K, Na and CEC	Evaluated concentration, ratio and base saturation
Organic carbon*	Walkley Black	Evaluated against natural grassland soil samples
Total Nitrogen and forms of N	Kjeldahl digestion and KCl extraction	
Phosphorus	Bray-1 (for acid soils)	Criteria will be determined by land use and or stadium of rehabilitation
Potential/exchangeable acidity (cover soil/coal discard)	Method described in USSA for exchangeable acidity and lime requirement	Measure if acidic conditions potentially exist.
Pyrite content (coal discard) and acid neutralising capacity	Costigan et al. (1981) and Smith et al. (1974)	Must be measured before rehabilitation commences and can be repeated before closure to determine risk for further acidification
Micro elements* (Fe, Mn, Al, Zn, Cu and other heavy metals)	EDTA or DTPA	Measure initially and if toxicity is expected (pH lower than 5.5)

Parameter	Method	Comments
Boron	Hot water extract	Measure initially and if toxicity is expected (pH lower than 5.5)
Particle size distribution (texture class)*	Clay: hydrometer method (Gee and Bauder, 1986)	Measure initially
Bulk Density*	Blake and Hartge (1986)	Measure initially and annually if cover soil has a high bulk density
Soil compaction and crust formation	Penetrometer (Bradford, 1986)	Measure initially and annually if cover soil has a high bulk density

4.5.   Further research area

The study only evaluated one maintenance strategy.   The results would have been more meaningful if similar rehabilitated dumps, but which are differently managed, were available to compare results with. It is proposed that a closer collaboration be developed between companies, business units/collieries to share and compare research experiences, to identify flagships that can be used to develop success criteria and to identify common areas of environmental concern that must be investigated.   During discussions with Anglo Coal and Ingwe Mine Closure Services it was clear that each company had its own philosophy and practices and have conducted trials on rehabilitation issues.

A comparison of different amelioration strategies to improve pasture vitality and production is needed especially considering the long-term ecological or land use objectives. Most research on the fertilisation and amelioration has been conducted in Europe and USA under different climatic conditions.

The use of combusted coal discard is proposed as buffer layer between cover-soil and uncombusted soils since it is relatively alkaline and will have a lower acid potential.   The use of combusted coal ash needs to be investigated to consider its effectiveness.

Research is needed to selected legumes that are able to maintain its vigour, improve nitrogen accumulation and that can be used in grazing systems.

A comparison of actual soil loss to the predicted soil loss calculated using the SLEMSA soil loss equation is suggested to determine the reliability of erosion predictions.

The influence of soil physical properties on organic matter accumulation, root development and general vegetation vigour need to be investigated.   Methods need to be investigated on how to improve soil structure and bulk density without disturbing the established vegetation.

5. REFERENCES

AKEN, M. 1998. Revegetation philosophy. (*In* IBC. Environmental rehabilitation in mining. Papers read at the IBC conference held at CSIR on 24-25 February 1998. Pretoria.)

ALEXIADES, C.A. & JACKSON, M.L. 1966. Quantitative clay mineralogical analysis of soils and sediments. *Clays and Clay Minerals*, 14: 35-52.

ANON. 1997. Guidelines for the establishment of Rehabilitation bonds for mining and Extractive industry. Minerals & Petroleum Victoria -May 1997 [Web:] http://www.nre.vic.gov.au/web/root/domino/cm_da/nrenmp.nsf/frameset/NRE+Minera ls+and+Petroleum?OpenDocument [Date of access: 8 December 2003].

ARSHAD, M.A. & MARTIN, S. 2002. Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems and Environment*, 88: 153-160.

ASKENASY, P.E. & SEVERSON, R.C. 1980. Chemical procedures applicable to overburden and minesoil. (*In* Hossner, L.R. Reclamation of surface-mined lands. Volume 1. Boca Raton, Florida, USA: CRC.)

BACKES, C.A., PULFORD, I.D. & DUNCAN, H.J. 1986. Studies on the oxidation of Pyrite in colliery spoil. I. The oxidation pathway and inhibition of the ferrous-ferric oxidation. *Reclamation and revegetation research*, 4: 279-291.

BANWART, W.L., BREMBER, J.M. & TABATABAI, M.A., 1972. Determination of ammonium in soil extracts and water samples by an ammonia electrode. *Communications in soil science and plant analysis*, 3: 449.

BARRETT, J. 1978. Vogels textbook of quantitative organic analysis. pp. 435-436.

BELL, F.G. 1996. Dereliction: colliery heaps and there rehabilitation. *Environmental engineering and geosciences*, 11: 85-96.

BELL, F.G., BULLOCK, S.E.T., HÄLBICH, T.F.J. & LINDSAY, P. 2001. Environmental impacts associated with an abandoned mine in the Witbank Coalfields, South Africa. *International journal of coal geology*, 45: 195-216.

BERG, W.A. 1978. Limitations in the use of soil tests on Drastically Disturbed Land. (*In* Schaller, F.W. & Suton, P. *eds*. Reclamation of Drastically disturbed Lands. Madison, Wisconsin, USA: American Society of Agronomy Crop Science of America and Soil Science Society of America. pp. 653-661.)

BERGMANN, W. 1992. Nutritional disorders of plants- development, visual and analytical diagnosis. Stuttgard: Gustav Fischer Verlag Jena 741 p.

BHPBILLITON. 2002. Health, Safety, Environment and Community report 2002: policy into practice. [web:] http://www.bhpbilliton.com/bb/sustainableDevelopment/reportsAndPolicies.jsp. [Date of access: 8 December 2003].

BLACK, C.A. 1965. Methods of Soil Analysis. Madison, Wisconsin, USA: American Society of Agronomy. 1372 p.

BLAKE, G.R. & HARTGE, K.H. 1986. Bulk Density. (*In* Klute, A. ed. Methods of Soil Analysis. Part 1: Physical and mineralogical methods 2nd edition. Agronomy no 9 (1). Madison, Wisconsin, USA: American Society of Agronomy pp 377-381.)

BRADFORD, J.M. 1986. Penetrability. (*In* Klute, A. ed. Methods of Soil Analysis. Part 1: Physical and mineralogical methods 2nd ed. Agronomy no 9 (1). Madison, Wisconsin, USA: American Society of Agronomy pp 463-477.)

BRADSHAW, A. 1997. Restoration of mined land-using natural processes. *Ecological Engineering*, 8: 255-269.

BRADSHAW, A.D. & CHADWICK, M.J. 1980. The Restoration of land. Oxford, London, UK: Blackwell.

BRADY, N.C. & WEIL, R.R. 1999. The nature and properties of soils. 12th edition. Upper Saddles River, New Jersey: Prentice Hall.

BRAUER, J.M. & WOLFSON, M.M., 1986. The influence of different forms and concentrations of nitrogen on the growth and metabolism of *Digitaria eriantha* and *Chloris gayana* grown under saline conditions. *Journal of the grassland society of Southern Africa*, 3(3): 113-116.

BREDENKAMP, G. & VAN ROOYEN, N. 1998a. Moist Clay Highveld Grassland. (*In* Low, A.B. & Rebelo, A.G. Vegetation of South Africa, Lesotho and Swaziland. Pretoria, RSA: Department of Environmental Affairs and Tourism. p. 40.)

BREDENKAMP, G., GRANGER, E. & VAN ROOYEN, N. 1998b. North –eastern Mountain Grassland. (*In* Low, A.B. and Rebelo, A.G. Vegetation of South Africa, Lesotho and Swaziland. Pretoria, RSA: Department of Environmental Affairs and Tourism. p 46-47.)

BRITISH STANDARD INSTITUTE. 1977. BS. 1016: methods for the analysis and testing of coal and coke. Part II. Forms of sulphur in coal.

BROWN, G.M.C. & GRANT, C.D. 2000. Nutrient status of pasture ecosystems established on rehabilitated overburden and topsoil sites in the Hunter valley, New South Wales. *Australian journal of soil research*, 38: 497-491.

BURLEY, J.B., THOMSEN, C.H. & KENKEL, N. 1989. Productivity equations fro reclamating surface mines. *Environmental Management*, 13: 631-658.

BUYS, A.J. 1986. MVSA bemestingshandleiding: 2nd ed. Hennopsmeer, RSA: Die Misstofvereniging van Suid-Afrika.

CARROL, C., MERTON, L. & BURGER, P. 2000. Impact of vegetation cover and slope on runoff, erosion and water quality for field plots on a range of soils and spoil materials on central Queensland coal mines. *Australian journal of soil research*, 38: 313-327.

CHAMBER OF MINES. 1981. Handbook of guidelines for environmental protection. Vol. 3. Johannesburg, RSA: Chamber of Mines.

CHARMAN, P.E.V. & ROPER, M.M. 1991. Soil organic matter. (In Charman, P.E.V. & Murphy, B.W. *eds.* Soils: their properties and management. A soil conservation handbook for New South Wales. Sydney, Australia: Sydney University Press. p. 206-214.)

COSTIGAN, P.A., BRADSHAW, A.D. & GEMMEL, R.P. 1981. The reclamation of acid colliery spoil. 1. Acid production potential. *Journal of applied ecology*, 18: 865-878.

CUMMINGS, R.W. & ELLIOTT, G.L. 1991. Soil chemical properties. (*In* Charman, P.E.V. & Murphy, B.W. Soils: their properties and management. A soil conservation handbook for New South Wales. Sydney, Australia: Sydney University Press. p. 193-205.)

DACEY, P.W. & COLBOURN, P. 1979. An assessment of methods for the determination of pyrite in colliery spoil. *Reclamation review*, 2: 113-121.

DE, S. & MITRA, K.A. 2002. Reclamation of mining generated wastelands at Alkusha-Gopalpur abandoned opencast project, Ranigani coalfield, eastern India. *Environmental geology*, 43: 39-47.

DENNINGTON, V.N. & CHADWICK M.J. 1978. The nutrient budget of colliery spoil tip sites. I. Nutrient input in rainfall and nutrient losses in surface run-off. *Journal of applied ecology*, 15: 303-16.

DINAUER, R.C. 1977. Minerals in soil environment. Madison, Wisconsin, USA: SSSA.

DORONILA, A.I. & FOX, J.E.D. 1990. Factors contributing to the presence and persistence of bare patches in pastures on a rehabilitated coal mine dump at Chiken Creek area 4, Collie. *Mulga research centre journal*, 10: 9-13.

EFROYMSON, R.A., WILL, M.E., SUTER, G.W. & WOOTEN, A.C. 1997. Toxicological benchmarks for screening contaminants of potential concern for effects on terrestrial plants. East Tennessee Technology Park, USA: US Department of Energy.

EPA, 1995. Rehabilitation and revegetation: Best practice in environmental management in Mining. Canberra, Australia: Environmental Protection Agency.

EVANS, K. 2000. Methods for assessing mine site rehabilitation design for erosion impact. *Australian journal of soil research*, 38: 231-247.

GAUCH, H.G. 1982. Multivariate analysis in community ecology. New York, USA: Cambridge University Press.

GEE, G.W. & BAUDER, J.W. 1986. Particle size analysis. (*In* Klute, A. *ed* Methods of Soil Analysis. Part 1: Physical and mineralogical methods 2nd ed. Agronomy no 9 (1). Madison, Wisconsin, USA: American Society of Agronomy, pp 383-409.)

HAIGH, M.J. 1998. Towards soil quality standards for reclaimed surface coal-mined Lands. *Advances in geo-ecology*, 31: 775-779.

HAVLIN, J.L., BEATON, J.D., TISDALE, S.L. & NELSON, W.L. 1999, Soil fertility and fertilisers: an introduction to nutrient management, 6th ed. Upper Saddle River, NJ, USA: Prentis Hall.

HEUER, B. 1991. Growth, photosynthesis and protein content in cucumber plants as affected by supplied nitrogen from. *Journal of plant nutrition*, 14: 363-373.

HOSSNER, L.R. 1980. Reclamation of surface-mined lands. Florida, USA: CRC Press.

IMES, A.I. & WALI, M.K. 1978. Government Regulations of reclamation in the Western United States: an Ecological perspective. *Reclamation review*, 1: 75-88.

JACKSON, M.L. 1958. Soil Chemical analysis. Englewood Cliffs, New Jersey, USA: Prentis Hall.

JONGMAN, R.H.G., TER BRAAK, C.J.F. & VAN TONGEREN, O.F.R. 1995. Data analysis in community and landscape ecology. Wageningen, Netherlands: Pudoc.

KEENEY, D.R. 1982. Nitrogen-availability indices. (*In* Page, A.L., R.H. Miller, R.H. & Keeney, D.R *eds* Methods of soil analysis part 2: chemical and microbiological properties. Agronomy series nr. 9(2). Madison, Wisconsin, USA: American Society of Agronomy. P. 711-734.)

KELLERMAN, T.S., COETZEE, J.A.W. & NAUDÉ, T.W. 1988. Plant poisonings and mycotoxicoses of livestock in Southern Africa. Cape Town, RSA: Oxford University Press.

KELLNER, K. & MORGENTHAL, T. 2003. The identification of the floristic composition and information indicators for the sustainable rehabilitation of ash disposal sites. (Report for ESKOM Matla Power Station). Potchefstroom: PU for CHE (Unpublished report).

KENT, M. 1982. Plant growth problems in colliery spoil reclamation. *Applied geography,* 11: 83-107.

KOTSIRAS, A., OLYMPIOS, C.M., DROSOPOULOS, J. & PASSAM, H.C. 2002. Effects of nitrogen from and concentration on the distribution of ions within cucumber fruits. *Scientia Horticulturae,* 95: 175-183.

LASA, B., FRECHILLA, S. LAMSFUS, C, & APARICIO-TEJO, P.M. 2001. The sensitivity to ammonium nutrition is related to nitrogen accumulation. *Scientia Horticulturae,* 91: 143-152.

LIMPITLAW, D., AKEN, M., KILANIM, J., MENTIS, M., NELL, J.P. & TANNER, P.D. 1997. Rehabilitation and soil characterization. (Papers read at 11th International Conference on Coal Research held in Calgary, Alberta. Calgary. pp. 297-309).

LOCH, R.J. & ORANGE, D.N. 1999. Changes in some properties of topsoil at Tarong-Coal Meandu Mine coalmine with time since rehabilitation. *Australian journal of soil research,* 38: 777-783.

LOOS, M.A., CLEGHORN, C. & MÖDINGER, H. 2000. Occurrence of bacteria causing acid mine drainage in the outer layers of coal waste dumps in relation to abiotic ecological determinants and soil cover used for dump rehabilitation. WRC report no. 454/1/00. Pretoria, RSA: WRC.

LOW, A.B. & REBELO, A.G. 1998. Vegetation of South Africa, Lesotho and Swaziland. Pretoria, RSA: Department of Environmental Affairs and Tourism.

MAYS, D.A. & BENGTSON, G.W. 1978. Lime and Fertiliser use in Land Reclamation in Humid Regions. (*In* Schaller, F.W. & Sutton, P. *eds.* Reclamation of Drastically disturbed Lands. Madison, Wisconsin, USA: American Society of Agronomy Crop Science of America and Soil Science Society of America)

MBENDI. 2002. Africa: mining-coal mining. [web:]
http://www.mbendi.co.za/indy/mining/coal/af/p0005.htm [Date of accessed: 15 October 2003].

MCGINNIES, W.J. & CROFT, K.A. 1986. Effect of N and P fertiliser placement on establishment of seeded species on redistributed mine topsoil. *Journal of Range Management,* 39: 118- 121.

MENGEL, K. & KIRBY, E.A. 1987. Principles of plant nutrition. Bern, Germany: International Potash Institute.

MENTIS, M.T. 1999a. Diagnosis of the rehabilitation of opencast coal mines on the Highveld of South Africa. *South African journal of science*, 95: 210-215.

MENTIS, M.T. 1999b. The Rehabilitation of disturbed land: environmental audit guide. Envirobiz Africa: Kloof.

MORGENTHAL, T.L. 2000. Vegetation dynamics and management models for coal-ash disposal sites at Hendrina Power Station, Mpumalanga, South Africa. Potchefstroom: PU vir CHO. (Thesis-PhD).

MORGENTHAL, T.L. & VAN RENSBURG, L. 2004. Ecosystem development on seven rehabilitated discard dumps. *African journal of range and forage science*. (in press)

MORGENTHAL, T.L., VAN RENSBURG, L., VAN DER WALT, I.J. & MEYER, R. 2003. An evaluation of topsoil quality on managed coal discard dumps. (*In* Society of South African Geographers. Geography as an Applied Spatial Science for Sustainable Development. Papers read at the 5th biennial congress of GSSA held in Bloemfontein on 21-23 September 2003. Bloemfontein. p. 45.)

MOTT, C.J.B. 1988. The inorganic component of the soil. (*In* Wild, A. *ed*. Russell's Soil conditions and plant growth. Essex, England: Longman. p. 213-238.)

MUNSELL. 2000. Munsell soil colour charts. New York, USA: GretagMacbeth.

NATIONAL RESEARCH COUNCIL, 1993. Soil and water quality. Washington, DC, USA: National Academic Press.

NELL, J.P. & STEENEKAMP, P.I. 1998. Final report: establishment of a soil profile database for rehabilitates opencast coal mined land. Report GW/A/98/78. Pretoria, RSA: ARC-ISCW.

OLESEN, S.E., ØVIG, J.K. & GRANT, R.O. 1983. The effects of sewage sludge and lime on revegetation of abandoned brown coal pits. *Reclamation and revegetation research*, 2: 267-277.

OLSENS, S.R. & SOMMERS, L.E., 1982. Phosphorus. (*In* Page, A.L., Miller, R.H. & Keeney, D.R. Methods of soil analysis part 2: chemical and microbiological properties, Agronomy, 9 (2). Madison, Wisconsin, USA: American Society of Agronomy. p. 403-427.)

PAGE, A.L., MILLER, R.H. & KEENEY, D.R. eds. 1982. Methods of soil analysis part 2: chemical and microbiological properties, Agronomy, 9 (2). Madison, Wisconsin, USA: American Society of Agronomy.

PALMER, J.P. & CHADWICK, M.J. 1985. Factors affecting the accumulation of nitrogen in colliery spoil. *Journal of applied ecology*, 22: 249-257.

PALMER, J.P., WILLIAMS, P.J., CHADWICK, M.J. MORGAN, A.L. & ELIAS, C.O. 1986. Investigation into nitrogen source and supply in reclaimed colliery soil. *Plant and soil*, 91: 181-194.

PANIAGUA, A., KAMMERBAUER, J., AVEDILLO, M. & ADREWS, A.M. 1999. Relationship of soil characteristics to vegetation succession on a sequence of degraded and rehabilitated soils in Honduras. *Agriculture, Ecosystems and Environment*, 72: 215-225.

PEOPLES, M.B. & BALDOCK, J.A. 2001. Nitrogen dynamics: nitrogen fixation inputs, the impact of legumes on soil nitrogen fertility and the contributions of fixed nitrogen to Australian farming systems. *Australian journal of experimental agriculture*, 41: 327-346.

PICHTEL, J.R., DICK, W.A. & SUTTON, P. 1994. Comparison of amendments and management practices for long-term reclamation of abandoned mine lands. *Journal of environmental quality*, 23: 766-772.

PIETERSE, P.A. & RETHMAN, N.F.G. 1995. Research note: level of nitrogen fertilisation and the dry matter yield of *Digitaria eriantha* cv. Irene in the Transvaal middleveld. *African journal of range and forage science*, 12: 87-88.

PIETZ, R.I., CARLSON, C.R., PETERSON, J.R., ZENZ, D.R. & LUE-HING, C. 1989. Application of sewage sludge and other amendments to coal refuse material: 1. Effect on chemical composition. *Journal of environmental quality*, 18: 164-169.

RAMIRIZ-MUNOZ, J. 1968. Atomic absorption spectroscopy and analysis by atomic absorption flame photometry. New York, USA: American Elsevier Publishing Co.

RETHMAN, N.F.G. & TANNER, P.D. 1993. Influence of soil fertility on botanical composition of rehabilitated pastures in South Africa. (Papers read at 10th National Meeting of the American Society for Strip Mining and Reclamation held in Spokane, Washington on 16-19 May 1993. Spokane, Washington. pp. 348-355.)

RETHMAN, N.F.G. & TANNER, P.D. 1995. Sustainability of grassland on rehabilitated strip mines in South Africa. (Papers read at Conference on Mining and the Environment held in Sudbury, Ontario held on 28 May to 1 June 1995. Sudbury, Ontario, Canada. pp. 1063-1069.)

RETHMAN, N.F.G. 1987. The effect of form and level of nitrogen fertilisation on the yield of *Digitaria eriantha*. *Journal of the grassland society of South Africa*. 4: 105-108.

RHOADS, J.D. 1982. Soluble salts. (*In* Page, A.L., Miller, R.H. & Keeney, D.R. *eds*. Methods of soil analysis part 2: chemical and microbiological properties, Agronomy, 9 (2). Madison, Wisconsin, USA: American Society of Agronomy. p 167-178.)

RIES, R.E. & HOFMANN, L. 1984. Pasture and hay land measures for reclamation success. *Minerals and the environment*, 6: 85-90.

RUSSEL, M.J. & ROBERTS, B.R. 1986. Revegetation of coal mine spoil using pasture on the Darling Downs of Queensland, Australia. *Reclamation and revegetation research*, 5: 509-519.

SABS. 1996. ISO 14001: Environmental management systems-specifications with guidance for use. Pretoria, RSA: The South African Bureau of Standards.

SANDOVAL, F.M. & POWER, J.F. 1977. Laboratory methods recommended for chemical analysis of Mined-land spoils and overburden in western United States. USDA Agriculture Handbook 525.

SCHAFER, W.M. 1979. Guides for estimating cover soil quality and mine soil capability for use in coal strip mine reclamation in western United States. *Reclamation review*, 2: 67-74.

SCHALLER, F.W. & SUTTON, P. *eds*. 1978. Reclamation Drastically Disturbed lands. Madison, Wisconsin, USA: American Society of Agronomy.

SCHOENHOLTZ, S.H., BURGER, J.A. & KREH, R.E. 1992. Fertiliser and organic amendment effects on mine soil properties and revegetation success. *Soil science society of America journal*, 56: 1177-1182.

SEAKER, E.M. & SOPPER, W. 1984. Reclamation of bituminous strop mine spoil banks with municipal sewage sludge. *Reclamation and revegetation research*, 3: 87-100.

SHORT, F.T., BURDICK, D.M., SHORT, C.A., DAVIS, R.C. & MORGAN, P.A. 2000. Developing success criteria for restored eelgrass, salt marsh and mud flat habitats. *Ecological engineering*, 15: 239-252.

SIEGEL, S. & CASTELLAN, N.J. 1988. *Nonparametric statistics for the behavioural sciences* (2nd ed.) New York, USA: McGraw-Hill

SINGER, M.J. & MUNNS, D.N. 1992. Soils: An introduction 2nd ed. New York, USA: Maxwell & Macmillan.

SKOUGSTAD, M.W., FISHMAN, M.J., FRIEDMAN, L.C., ERDMAN, D.E., & DUNCAN, S.S. 1979. Methods for determination of inorganic substances in water and fluvial sediments. Book 5. (In: Techniques of water resources investigation of the United States geological survey. Washington, D.C. U.S.: Geological Survey.)

SMITH, R.M., GRUBE, W.E. JR., ARKLE, T. JR. & SOBEK, A. 1974. Mine Spoil Potentials for Soils and Water Quality. Washington, D.C, USA: Environmental Protection Technology Series EPA-670/2-74-070. 302 pp.

SMYTH, C. & DEARDEN, P. 1998a. Attitudes of environmental management personnel involved in surface coal mine reclamation in Alberta and British Columbia, Canada. *Applied geography*, 18: 275-295.

SMYTH, C. & DEARDEN, P. 1998b. Performance standards and monitoring requirements of surface coal mine reclamation success in mountainous jurisdictions of western North America: a review. *Journal of environmental management*, 53: 209-229.

SOBEK, A.A., SCHULLER, W.A., FREEMAN, J.R. & SMITH, R.M. 1978. Field and laboratory methods applicable to overburden and minesoils, EPA-600/2-78-054. Cincinnati, USA: Environmental Protection Agency.

SOIL CLASSIFICATION WORK GROUP. 1991. Soil classification: a taxonomic system for South Africa. Pretoria, South Africa: The Department of Agricultural Development.

SOUTH AFRICA. 1991. Minerals Act, 50 of 1991. Pretoria, RSA: Government Printer.

SOUTH AFRICA. 1998. National Water Act, 36 of 1998. Pretoria, RSA: Government Printer.

SOUTH AFRICA. 2002. Mineral Resource and Development, Act 28 of 2002. Pretoria, RSA: Government Printer.

STATE OF VICTORIA. 2002. Primary industries: Minerals and Petroleum. Mineral Resource Development Act of1990. [web:] http://www.dpi.vic.gov [Date of access: 27 October 2003].

STATSOFT, INC. 2003, STATISTICA (data analysis software system), version 6. [web:] www.statsoft.com.

STROHMENGER, P.H.E., CLAASENS, A.S., MENTZ, W.M. & BARNARD, R.O. 1999. Interactive effects of sulphate-dominated salinity and fertility in wheat (*Triticum aestivum* L.). (Paper read at the 22nd congress of the Soil Science Society of South Africa held in Pretoria during 28 June to 1 July 1999. Pretoria.)

SYDNOR, M.E.W. & REDENTE, E.F. 2002. Reclamation of high-elevation acidic mine waste with organic amendments and topsoil. *Journal of Environmental quality*, 31: 1528-1537.

TANNER, P. 1998. Land Rehabilitation-soil handling and land capability aspects. (*In* IBC. Environmental rehabilitation in mining. Papers read at the IBC conference held at CSIR on 24-25 February 1998. Pretoria.)

TAYLOR, R.K. & SPEAR, D.A. 1972. The geotechnical characteristics of a spoil heap at Yorkshire Main Colliery. *Journal of engineering geology*, 5:243-263.

TER BRAAK, C.F. & ŠMILAUER, P. 1998, *CANOCO* Reference Manual for user's guide to CANOCO Community Ordination ver. 4. Ithaca, NY, USA: Microcomputer Power,

THOMAS, G.W. 1982. Exchangeable cations. (*In*. Page, A.L., R.H. Miller, R.H. & Keeney, D.R *eds*. Methods of soil analysis part 2: chemical and microbiological properties. Agronomy series nr. 9 (part 2). Madison, Wisconsin, USA: ASA/SSSA.)

TODD, M.C.L., GRIERSON, P.F. & ADAMS, M.A. 2000. Litter cover as an index of nitrogen availability in rehabilitated mine sites. *Australian journal of soil research*, 38: 423-433.

VAN DER WATT, H. & VAN ROOYEN, T. 1990. A glossary of soil science. Pretoria, RSA: The Soil Science Society of South Africa.

VAN RENSBURG, L. & MORGENTHAL, T.L. 2003. The evaluation of water treatment sludge as ameliorant for acid mine waste. *Journal of environmental quality,* 32: 1658-1668.

VAN WYK, S. 1994. `n Strategie vir die rehabilitasie van versteurde mynbougebiede in Suiderlike Afrika. Potchefstroom: PU vir CHO. (Thesis-PhD).

VENTER, H. 2003. Fertiliser Handbook 2003. Pretoria, RSA: The Fertiliser society of South Africa (FSSA).

VOGEL, W.G. & CURTIS, W.R. 1978. Reclamation research on coal surface-mined land in the humid east. (*In* Schaller, F. and Sutton, P. *ed.* Reclamation of drastically disturbed land. Madison, Wisconsin, USA: ASA/CSSA/SSSA. p. 379-395.)

WALI, K.M. 1999. Ecological succession and the rehabilitation of disturbed terrestrial ecosystems. *Plant and soil*, 213: 195-220.

WALKLEY, A. 1935. An examination of methods for determining organic carbon and nitrogen in soils. *Journal of agricultural science*, 25: 598-609.

WALTON, C. 1984. Reader's Digest Atlas of South Africa. Cape Town, RSA: Readers Digest.

WATES, J.A. & RYKAART, E.M. 1999. The performance of natural soil covers in rehabilitating opencast mines and waste dumps in South Africa. WRC report 575/1/99 Pretoria, RSA: Water Research Commission.

WHITTIG, L.D. & ALLARDICE, W.R. 1986. X Ray diffraction techniques. (In Klute, A. ed. Methods of soil analysis part 1: physical and mineralogical methods. Agronomy 9 (1) Madison, Wisconsin, USA: ASA & SSSA.)

WILLIAMSON, N.A., JOHNSON, M.S. & BRADSHAW, A.D. 1982. Mine Waste Reclamation. London, UK: Mineral Industry Research Organisation.

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY. 1994. Guideline 1: topsoil and overburden. [web:] http://deq.state.wy.us/lqd.htm. [Date of access: 23 January 2003].

Appendix A: organic analysis results from two kraal manure samples collected at Witbank and Ogies dumps during the 2002 maintenance. The kraal manure originated from a feedlot in the Middleburg area.

		Sample A	Sample B	Average
pH		7.78	8.2	8.0
EC	mS.m^{-1}	374	312	343
C/N		8	9	8
Moisture		26	22.9	24.450
C		6.320	6.49	6.405
N		0.834	0.717	0.776
P		0.950	0.783	0.867
Ca		0.970	0.85	0.910
Mg		0.360	0.25	0.305
K	%	0.952	0.771	0.862
Na		0.113	0.096	0.105
Fe		2.000	2.13	2.065
Cu		0.029	0.028	0.029
Mn		0.312	0.325	0.319
Zn		0.098	0.085	0.092
Ca:Mg:K:Na		41:15:40:5	43:13:39:5	42:14:40:5

Appendix B: An evaluation of topsoil quality on managed coal discard dumps
Abstract from paper presented at the biennial congress of the Society of South African Geographers held at University of the Free State, Bloemfontein on 21-23 September 2003 (presentation included in accompanying CD).

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Coal discard dumps at colliery operations are associated with major environmental impacts, including acid mine drainage, ground water pollution, salinisation and spontaneous combustion. To ensure the minimization of environmental impacts it is crucial that the end result after rehabilitation is effective. Covering by a topsoil layer and the revegetation with a seed mixture are currently regarded as the most successful rehabilitation methods. The viability of the soil cover on rehabilitated discard dumps, to sustain vegetation is, however, questioned. This study assessed the chemical degradation of topsoil on seven rehabilitated coal discard dumps. A further objective of the study was to evaluate the current rehabilitation methods and maintenance practices influence on topsoil quality.

Chemical analyses indicated that topsoil salinity on all but one rehabilitated dump was comparable to that of surrounding soils salinity (EC 22 mS.m^{-1}). Topsoil electrical conductivity (EC) on six of the seven dumps was between 22 and 40 mS.m^{-1}. Topsoil pH (pH between 5.6 and 7.7) was higher than that measured for surrounding soils (pH between 4.6 and 6.9) and therefore more alkaline. The topsoil acidity and salinity increased (pH lower than 5; EC higher than 200 mS.m^{-1}) at the topsoil–coal contact zone in comparison to the topsoil surface. During the three-year monitoring period the topsoil acidity and salinity remained, on average, constant. Macro element concentrations (calcium, magnesium, potassium, phosphate and nitrogen) were constant during the three-year study period or increased at some dumps. The strong correlation between calcium, magnesium and sulphate ions indicated that salts would precipitate in the form of calcium and magnesium sulphates.

The low-level fertilisation programme applied was successful to maintain the soil fertility and prevent further decline in soil quality. The application of lime is a major

contributor to increase salinity on the dumps that were surveyed. Topsoil acidity could have originated from the borrowed soil and not necessarily from the underlying coal. The study indicates the importance of occasional chemical analysis of deeper topsoil to identify potential problems. Results confirm the importance of correct selection of soils for topsoil, the importance of topsoil sampling and the correct application of fertilisers. Rehabilitation is also not a "walk away solution" but must be managed and monitored to ensure the development of a self-sustaining ecosystem.

(15-minute oral presentation)