Proceedings of the 11th International Conference on Coal Research, Calgary, 9-12 September, 1997, pp 297-309

Rehabilitation and soil characterization.

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ABSTRACT

Mined land should be rehabilitated to a stable state, compatible with the surrounding landscape. To achieve this, a sound understanding of the nature of minesoil is required. Minesoil is often inhospitable to vegetation due to a combination of physical and chemical factors. A survey conducted by the Institute for Soil, Climate and Water indicates that elevated levels of compaction in minesoil and the presence of acidity are frequently responsible for poor vegetation cover on rehabilitated land. Conventional agricultural techniques for the remediation of acid soils are often insufficient and additional measures are thus necessary. Such measures may include irrigation of minesoil with limed mine water. The physical and chemical characteristics of minesoil are discussed and then a grading system for soils associated with rehabilitated land is presented. The grading system is currently used on collieries belonging to the Ingwe Coal Corporation and provides a practical method for mines to assess their rehabilitation performance. The system grades land according to a 5 point scale under the headings landscape quality and soil fertility.

1. INTRODUCTION

Globally, some 500 000 hectares of land are directly disturbed by mining each year (Young, 1992, in Johnson & Lewis, 1995). This disturbance consists of both the excavation of surface strata and the deposition of sub-economic ores and waste material.

Areas disturbed by mining are highly susceptible to erosion due to a lack of vegetation, steep slopes and the presence of fine, dispersed particles (Chisholm & Dumsday, 1987). Eroded materials from dumps and spoil piles may be deposited in neighbouring streams or on adjacent farmlands, reducing the economic potential of these resources. Current best practice requires the revegetation of land disturbed by mining as this reduces percolation of water through the dumps and spoils, stabilises the surface and can even make previously disturbed areas available for an alternate land use.

Coal has been mined in South Africa since the turn of the century. The early handgot, bord and pillar workings were gradually replaced with mechanised operations and by the 1970's, extensive strip mining of coal had become widespread. This form of extraction allows optimal exploitation of the reserve, but also completely destroys the land surface. The South African coal industry has practised extensive rehabilitation for the last two decades. This has been a largely self-motivated activity. The Chamber of Mines of South Africa has developed extensive guidelines to assist collieries in this regard, the fundamental premise of effective rehabilitation being that mined land must be restored to to it's pre-mining landuse potential as closely as possible.

Heightened awareness of the environment throughout the industry has lead to increasingly scientific methods being applied to the rehabilitation of mined land. The characterization of minesoil has been recognized as a particularly important parameter in the long term stability of rehabilitated land.

This paper reports on some of the concepts guiding best practice rehabilitation in South Africa today.

2. PHYSICAL PROPERTIES OF REHABILITATED LAND

It is necessary to revegetate previously mined land with plant species that will not only control erosion, but also provide vegetative diversity. These species should, through succession, contribute to a stable and compatible ecosystem (Tewary, Singh & Dhar, 1996). Critical to the successful establishment of vegetation is an understanding of the nature of minesoils in rehabilitated landscapes as these differ from natural soils in respect of depth, density, drainage, organic material content, fertility and microbial activity (Rethman & Tanner, 1993).

During 1994, personnel of the Institute for Soil, Climate and Water (ISCW) visited mines of the Trans-Natal, Randcoal and Amcoal groups. Profile pits prepared by the various mining companies were described and some were sampled for soil analysis.

A block containing 34 profiles was described at Kleinkopje Colliery near Witbank in Mpumalanga. The bulk densities of the majority of the soils are very high, severe compaction generally occuring between 200 mm and 600 mm soil depth.

The high values found are in accordance with field observations. It was regularly found, during profile description, that the density of the soil had a pronounced adverse effect on root development of the plants growing in the soil. Where the soil was highly compacted, root growth was almost entirely confined to cracks and cleavage planes.

The conventional tool for describing soil compaction is bulk density which in its simplest form is defined as the dry mass per unit bulk volume of the soil **(Harris, 1971)**. Soil compaction is a densification of the soil under unsaturated conditions **(Bradford & Gupta, 1986)**. According to **Hillel (1980)**, soil layers may be considered to be compacted when the porosity is such that aeration is restricted or when the soil is so dense, and its pores so small, that root penetration and drainage are impeded. Under these conditions, infiltration and hydraulic conductivity are also impeded.

A further manifestation of soil compaction is the difficulty it creates with respect to soil management, particularly tillage. Experience on rehabilitated land in Mpumalanga has suggested that deep ripping of replaced top soil is required. Conventional ripping techniques result in loosening of topsoil down to 600 mm. Below this, consolidated material is present. This results in the water-logging of roots and subsequent stunted growth of vegetation.

Associated with soil compaction is hard setting, which is also a common phenomenon on the rehabilitated mine soils which were investigated. Soils displaying hard setting characteristics appear compact and very hard, with an apparently apedal structure, but are soft when wet.

The high bulk densities between 200 and 600 mm, in the soils investigated, indicate that the initial compaction which occurs during soil emplacement is not effectively alleviated by mechanical means. If the formula of **Bennie (1979)** for maximum compaction is applied, a value in the region of 2 300 kg.m^3 is obtained for the cover soils in question. Some of these soils thus seem to be close to their maximum compaction.

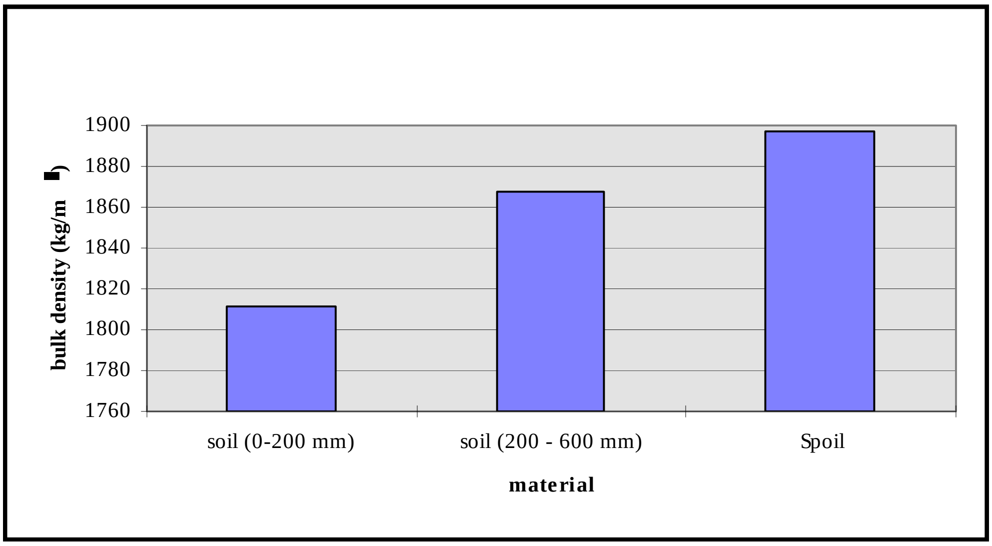

Figure 1. Mean bulk densities of minesoils sampled in Mpumalanga (after Nell & Steenekamp, 1996).

The regression equation of **Van Huyssteen (1989)** for penetrometer soil strength as a function of bulk density of a sandy loam soil was applied. Using this method, the median soil strengths at 0-200 mm , 200-600 mm and the spoil are 2 760 kPa, 3280 kPa and 2 862 kPa respectively. According to Van Huyssteen (1989) penetrometer soil strength values of 2 000 kPa to 2 500 kPa have generally been reported as representing critical penetration resistance, depending on various crops and penetrometer probes. No values are reported specifically for forage crops.

The problem of compaction is not unique to the rehabilitation of South African opencast coal mine soils. According to King (1989) and Davies *et al.* (1982), soils restored after opencast coal mining generally suffer from problems associated with compaction and decreased subsoil permeability.

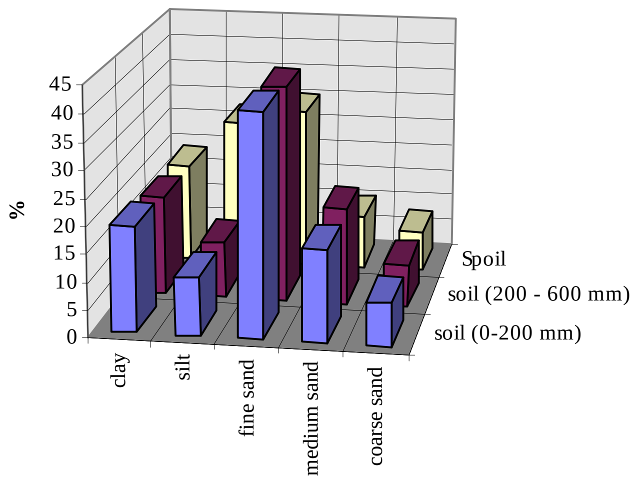

Figure 2. Mean composition of minesoils on rehabilitated mine lands in Mpumalanga (after Nell & Steenekamp, 1996).

3. CHEMICAL PROPERTIES OF REHABILITATED LAND - SOIL ACIDITY

The oxidation of metal sulphide ores extracted by mining operations can result in acidification of the adjacent soil. If pyrite (FeS_2) is present in significant quantities, oxidation of this and other sulphides results in the generation of sulphuric acid (H_2SO_4). When *in situ* neutralising capacity is inadequate to neutralize the generated acidity, surplus acid remains that can affect soil materials.

In normal agricultural soils, standard techniques for measurement of soil acidity and lime requirements involve the measurement of total acidity present and calculation of lime needed for neutralization. Normal agricultural techniques for predicting lime requirement are inadequate as they under estimate quantities of lime needed. There are probably two reasons for this: firstly, standard techniques have been developed for natural soils where pH values rarely drop below 4.0. Minesoils on occasion drop as low as pH 2.5 and the neutralization requirements of the aluminium, iron and manganese species present may not be accounted for in standard tests. Secondly, minesoils often contain significant quantities of sulphide minerals that are undergoing oxidation. In this situation there is a need to estimate both the existing acidity and that which will be generated in the future. This depends on total quantities of acid-generating and acid-neutralizing minerals that are present, and the rate at which these minerals react.

Where severe soil acidification has taken place as a result of mining, the visual effects are dramatic. Mining acidity is normally confined to clearly demarcated zones which are related to clearly defined mining activities. In Mpumalanga, severe acidity has only affected relatively small areas. One of the large companies operating in this area, Amcoal, reports that less than 100 ha out of 70 000 ha of Amcoal-owned land has severely acidified soil.

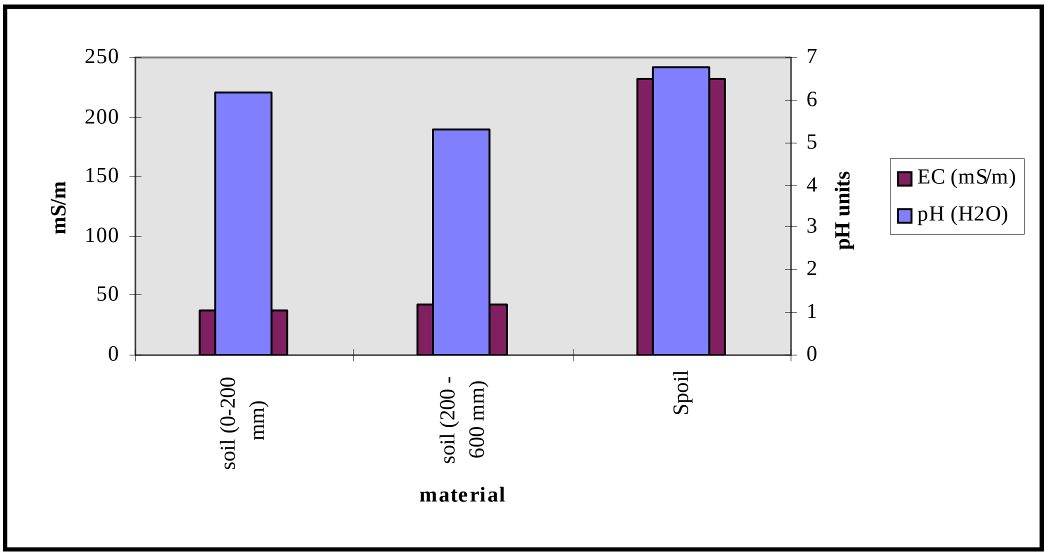

Figure 3. Selected chemical characteristics of rehabilitated minesoils in Mpumalanga (after Nell & Steenekamp, 1996).

Relatively large areas of stable soils have been disturbed by opencast mining for coal. Of the total of 2.7 million ha of agricultural land that is underlain by coal reserves in the Mpumalanga highveld, less than 7% may ultimately be mineable by opencast methods. Further, the proportion of rehabilitated soils that can be regarded as acidified as a result of opencast mining activity is low. In recent years, the ISCW has been evaluating rehabilitated minesoils. By February 1996 some 576 profile pits had been dug in rehabilitated land. The cover soils did not differ significantly, in terms of acidity, from their natural neighbours. Further, the underlying spoil materials did not show soil acidity to be a major current problem.

Table 2
Soil acidity in rehabilitated coal minesoils (Nell & Steenekamp, 1996)

Soil Depth (mm)	Sample Size	Average pH value (H_2O)
0 - 200 (soil)	128	6.15
200 - 600 (soil)	79	5.70
600 - 900 (spoil)	190	6.39

Clearly, although some rehabilitated soils have underlying spoil that is acid, in the majority of cases, the underlying spoil materials are either not significantly acid, or they are neutral.

Critical to the prevention of generation of acidity is exclusion of oxygen from the exposed sulphide minerals. A number of techniques have been developed that are effective. These include the use of either water or soil covers to minimise oxygen movement into the affected zones. Both international experience **[ref?]** and locally conducted trials undertaken as part of a Water Research Commission project **[ref?]** have shown that soil covers, correctly constructed, can markedly decrease the amount of oxygen that moves into the underlying acid-generating material. This in turn decreases the amount of acid generated

3.1 The Nature and Consequences of Minesoil Acidity

Acid minesoils and natural soils that have been acidified by acid mine waters may differ significantly from soils that have been acidified by injudicious application of fertilizer or by acid rain. These differences are reflected in at least three different ways:

- Severely acidified minesoils may be much more acid than those normally found in agricultural areas. In some instances, pH values on minesoils as low as pH 2.0 to 3.0 have been measured. This is reflected in large concentrations of soluble iron, manganese and aluminium.
- There is some evidence that the action of strong acid may alter the nature of clay materials present. Work in Germany **[ref?]** has indicated that clay particles may become "etched", and field experience has shown that acid water soon converts impermeable clays to permeable clays. The effects of these modifications on the physical and chemical characteristics may be considerable, but have not been quantified yet for South African soils.
- Although acidification in normal soils is accompanied by low concentrations of Ca and Mg, in the majority of minesoils Ca and Mg are present in ample supply. This may radically affect the ability of crops to survive in acid conditions, and there are records of lucerne growth on the Mpumalanga Highveld on mines of pH 4.0 (KCL).

3.2 Irrigation with Gypsiferous Mine Waters - A Possible Solution to Acid Subsoil Problems on the Mpumalanga Highveld.

Recent work by Barnard *et al.*, (1996) indicates that neutralized acid mine waters have considerable potential for use in irrigation of a range of agronomic crops. Although the project was directed at establishing crop sensitivity to these waters, the limited amount of soil work done indicated that the influence of gypsiferous water on soil pH, Ca and SO_4 values was not restricted to the upper 200 mm of the profile, and it is believed that the potential exists to increase subsoil pH considerably by irrigation with neutralised mine waters.

Further experimentation is currently underway at Kleinkopje Colliery to make a detailed evaluation of the influence of irrigation with neutral calcium and manganese-sulphate rich water on soil characteristics and drainage water quality. The project will run from 1997 to 2000 and should provide clear indication of the effects of gypsiferous mine waters on subsoil acidity.

Soil pH and phosphorus status have been reported as key requirements for the maintenance of plant vigour (Rethman & Tanner, 1993).

3.3 Implications of Rehabilitated Land for Vegetation

Over an experimental period of 5 years (1987-1992) it was found that of the seeded species, the annual *Eragrostis tef* and weakly perennial *Chloris gavana* disappeared completely, irrespective of level of fertility, whereas the perennial *Digitaria eriantha* persisted as the dominant species, irrespective of soil acidity, phosphorus or potassium status. In contrast, *Medicago sativa* was extremely sensitive to low pH, phosphorus or potassium and was completely eliminated under such conditions. (Rethman and Tanner, 1993).

4. ASSESSMENT OF REHABILITATED LAND

4.1 Approach

Standards have been developed to evaluate rehabilitation performance. These are not of the single-value, pass-or-fail type, but are graded standards to permit scoring performance over a range.

The present graded standards have 5 levels:

1. **best environmental practice** is recognition of truly excellent rehabilitation performance,
2. **good environmental practice** is a level of performance which authorities are likely to compliment, or it is a level that may reasonably be deduced from current wisdom and environmental practice of a high international standard,
3. **fair environmental practice** is a level of performance possibly acceptable for closure regarding historical rehabilitation, but not good enough for new rehabilitation,
4. **poor environmental practice** is flawed rehabilitation that does not comply with the ethic of sustainable living,
5. **non-environmental practice** is a class reserved for cases where no environmental management is practised.

Two areas of standards are considered here.

Landscape quality

- land capability
- soil loss hazard
- general form of the landscape

Soil fertility

- macro- and micro-nutrients commonly determined in soil analysis

4.2 Landscape quality

4.2.1 Land capability

This is the capacity to meet the needs of one or more types of use as determined by a specified land capability assessment technique. These standards assume that the land capability prior to mining was established, and that the environmental management programme report (EMPR) lays down:

- the extent of each land capability order to be reinstated, and
- which sections of the reinstated landscape will be restored to a specified land capability order.

Table 2
Environmental practice grading scheme

Category	**Score**	**Level of environmental practice**
Required land capability fully restored or improved	5	Best
Minimum hectareage of land capability met but land not smooth and with localized humps & hollows	4	Good
Minimum hectareage of wetland, arable land and grazing land not met but within 10% of requirements	3	Fair
Minimum hectareage of wetland arable land and grazing land not met within 10% of requirements	2	Poor
or Excess land relegated to wilderness category because of excessive slope	2	Poor
Unrehabilitated	1	Non-performance

4.2.2 Soil loss hazard

This is determined quantitatively using a soil-loss model. The scoring of the modelled losses in tons per hectare per year is as in the table below. The input of vegetal cover is the present cover, or the average vegetal cover of neighbouring land not disturbed by mining, whichever is the lesser.

Table 3
Soil loss hazard grading scheme

Category	Score	Level of environmental practice
≤2 $t.ha^{-1}.a^{-1}$	5	Best
≤4 $t.ha^{-1}.a^{-1}$	4	Good
4<8 $t.ha^{-1}.a^{-1}$	3	Fair
8<12 $t.ha^{-1}.a^{-1}$	2	Poor
>12 $t.ha^{-1}.a^{-1}$	1	Non-performance

Preserving a viable topsoil is regarded as a key aspect of rehabilitating mining-disturbed land. The topsoil over the underlying spoils represents a thin layer of favourable growing medium for plants. The conventional view is that the underlying spoils are expected to take decades to centuries to weather, and in the meantime represent a more or less inhospitable environment for plants.

The natural rate of soil loss on non-disturbed land is estimated to be of the order of 1 ton per ha per year. The inherent rainfall erosivity of the Mpumalanga Highveld is high, and on a geological time scale would rapidly bevel any protrusions above the landscape, unless these were of hard rock. This is reflected in the present-day gently rolling landscape. The rate of soil formation is hard to measure, but the order of magnitude in most instances is 1 to 10 $t.ha^{-1}.a^{-1}$.

In protecting mining-disturbed land from raindrop impact and overland flow of water, there are only three aspects that land managers can control. These are the steepness of slope, the length of slope, and the protective plant cover over the soil.

The rationale of the soil loss standards is that the design of the rehabilitated landscape is such that the specified rate of loss will not be exceeded in the long term, even if the vegetal cover falls from the 90% or more of cultivated pastures to the normal 50% or so for undisturbed veld of the Mpumalanga Highveld.

4.2.3 General landscape form

The general landscape form is assessed on several criteria. In the ideal the following should apply:

- the general land-form should be smoothly undulating, conforming to the pre-mining condition,
- the lower landscape should be concave, not convex,
- the surface must be shaped so that water drains freely,
- there must be an approved drainage plan, and the landscaping must comply with it,
- the soil conservation works - including grassed waterways and contour banks - must be designed to fit the particular landscape, and they must be maintained.

Reinstating the former appearance of the landscape is not only of aesthetic significance - an important consideration in its own right. The form of the unmined landscape was moulded by natural geomorphic agents which will reshape unnatural post-mining landscapes. Reinstated landscapes that look natural and aesthetically appealing are likely to be more stable than unnatural land forms.

Table 4
General landscape form grading scheme

Category	**Score**	**Level of environmental practice**
Landscape smooth, lower part concave; compliance with drainage plan; designed contour banks & grassed waterways present and maintained.	5	Best
Only minor deviations from the ideal.	4	Good
Rehabilitated landscape deviates substantially from the ideal but landscape stability could be preserved under good pasture or veld management.	3	Fair
Landscaping is defective to the degree that landscape stability cannot be preserved even under the best pasture or veld management.	2	Poor
No proper landscaping.	1	Non-performance

4.3 Soil fertility

Ideally the rehabilitated land will pass through a period of 5 years of elevated fertility. After this 5-year period the nutrient status of the soils may be maintained or allowed to deplete, depending on whether the land-user wants to keep a high-production pasture or permit oldfield succession to proceed, so that the vegetation reverts to veld. The standard is applied to all macro- and micro-nutrients commonly analyzed (P, K, Ca, Mg, Zn), as well as to soil acidity.

Rehabilitating mining-disturbed land involves establishing a complete and vigorous cover of perennial grass. There are several reasons for this:

- grass is the best natural cover for protecting against soil loss,
- grass has a high turnover of roots, which provides the medium for restoring normal soil functioning by an input of organic matter,
- grass has a high utility value.

Table 5
Soil fertility grading scheme

Category	**Score**	**Level of environmental practice**
No fertility deficiency since establishment if pasture < 5 years old, or for first 5 years if > 5 years old.	5	Best
Fertility deficiencies other than P and/or acidity excess have occurred but for no more than one season up to pasture age of 5 years.	4	Good
P-deficiency and/or excess acidity have occurred when pasture 0-5 years old, but not for longer than one year.	3	Fair
At some time during first 5 years fertility requirements were met.	2	Poor
The fertility requirements were never met when pasture was 0-5 years old.	1	Non-performance

Initial high soil fertility is required to achieve a good cover of grass to protect from soil loss. In rehabilitating mining-disturbed land the replaced "topsoil" (often it is not proper topsoil) is patchy in sand, silt and clay fractions, in fertility, in pH, in depth, in amount of inclusions of unweathered rock and sulphide-containing spoils, etc. Natural recolonization by plants would generally also be patchy, with a serious risk of catastrophic soil loss from slow-to-colonize areas. The initial high soil fertility promotes incorporation of organic matter into the soil via the turnover of grass roots. In the grass plant the amount of root is proportional to the amount of aerial part. To support vigorous above-ground plant growth, there must be equally vigorous underground growth to assimilate moisture and nutrients.

Classically, nitrogen (N) and phosphate (P) are limiting nutrients that constrain plant production. There is a certain amount of natural input of N. However, some grasses are very responsive to N fertilization, provided that other essential nutrients are not deficient. Principal among these other nutrients is P. Highveld soils are notorious for their low P levels. Aggravating the infertility of Highveld soils is their natural acidity leading to aluminium toxicity.

The soil fertility standards are rationalized on the basis of restoring the soil-vegetation function. Once achieved, the artificial input of nutrients can be stopped. The pasture then passes through a sequence of change back towards veld. On the Highveld oldfield succession probably spans 50 to 100 years.

The utility value of planted grass pastures, and the grazing value of some native pastures, may be improved by application of fertilizers, particularly N and P. The main effects of applying fertilizers are to boost production and to increase the quality of the forage to the grazing animal. The post-mining land-user may elect to maintain the revegetated land as high-production pasture, in which case a pasture maintenance fertilizer program would be applied. The decision to go back to veld or to maintain the high-production pasture is essentially an economic one, depending on relative costs of inputs and values of outputs. The scoring in relation to the soil fertility standards is geared for the pulse of fertility with subsequent decline. There is no penalty in the present scoring method for high fertility maintained for many years after establishment, even in perpetuity.

5. CONCLUSION

Although less than 3% of South Africa's surface area is disturbed by mining, the impact on this area is significant. The increasingly scientific methods applied to rehabilitation ensure a continually improving level of performance. This is critical in the light of increasing public and government pressure on the industry.

Acidity effects, where they occur, may be extreme, and the nature of minesoil acidity differs from that encountered in normal agricultural soils. The possibility exists that irrigation with gypsiferous mine waters may help ameliorate subsoil acidity on the Mpumalanga highveld.

Mining is a temporary land use and therefore great onus is placed on the industry to rehabilitate land. Properly rehabilitated mined land offers advantage that few other forms of landuse can compete with - secondary use.

The limited amount of land available to agriculture in South Africa makes the destruction of prime agricultural land in Mpumalanga even less acceptable and therefore the importance of a scientific approach to soil characterization cannot be overstated.

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