The Impact of Surface Coal Mining on the Pre- and Post-Mining Agricultural Potential of the Grassland Biome of Southern Africa

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Abstract. Surface mining of coal is widespread in the grassland areas of the Mpumalanga Province in South Africa, and is the main cause of many environmental impacts in this agriculturally important region. To ensure healthy and productive vegetation after the reclamation process, disturbed soils need to be ameliorated and re-vegetated with locally adapted grass species to protect, preserve and improve soils for future agricultural use. To date, soil compaction is regarded as one of the main factors that cause severe restrictions in the effective rooting depth of plants, and the level of compaction is strongly influenced by altered soil water contents, soil texture, soil structure and often non-existing organic matter contents. Imported organic materials and enhanced plant root development may lead to reduced effects of soil compaction and an increased amount of moisture in the soil profile, which becomes available for plant growth during the growing season. This research focussed on the various amelioration aspects to alleviate and mitigate soil compaction to promote sustainable vegetation establishment and production to reinstate the agricultural potential of the disturbed environment. With associated soil amelioration, an increase in biomass production, of selected plant species was noted to be 52% higher on soil that was amended with 40 t/ha of organic amendment, in comparison to the soil that did not receive any. The correct selection of species with a known root structure and basic management requirement has, therefore, the potential to be useful in creating an organically rich, alleviated and more sustainable soil environment to ensure improved rehabilitation results of surface coal mines. It can be concluded, that sufficient data has shown that reclaimed surface coal mine soils can serve as a valuable resource to the animal production industry as well as to local communities, if managed correctly.

Keywords: Surface coal mine reclamation, grassland, agricultural potential, planted pastures, animal production.

Introduction

To generate knowledge, disseminate information and ultimately educate and feed a nation requires energy. Unfortunately we live in an energy driven economy, of which mining is the backbone. In South Africa, it is evident that our cheapest source of energy today to meet our growing population's demand for years to come is derived from coal. Mining these resources will continue until cheaper alternatives emerge. The question however can be asked: at what expense? Feeding a growing population also requires good agricultural land, which should receive the same, if not more attention, as the mining of the coal reserves is increasing, but our best quality land for food production is diminishing! Industrial operations such as opencast coal mining are regarded as the main cause of many negative impacts on the environment, and as such have lately been receiving a lot of attention in the media. However, another burning question is can we, if and when required, recover the land after mining has taken place and restore it to agricultural use? Opencast mining of coal is widespread in the grassland areas of Mpumalanga and KwaZulu-Natal and moving into the drier savannah regions of the Limpopo Province in South Africa. These provinces are also home to many important agricultural production systems that contribute to the national objective to ensure food security. Grasses depend on an abundance of plant available nutrients for survival and good productivity. In South Africa, surveys on reclaimed areas have revealed that soil compaction has imposed severe restrictions on the effective rooting depths of most reconstructed soils. Compaction causes an increase in the soil bulk density and coupled with this is an increase in soil strength (Whalley *et al*. 1995) and a decrease in soil porosity (Yin Chan 2006). Soil strength indicates the resistance that the soil offers against the growth of plant roots (Conrad *et al*. 2002). Tripathi and Singh (2004) reported that the application of manure improved soil physical properties and nutrient capacity of the soil and increased plant growth. The increased cover, productivity and yields of plants growing on such soil, extends nutrient cycling in the ecosystem and ensures sustainability without the need for continuous inputs into fertilization (Rethman 2006). Haynes and Naidu (1998) also reported that increased root growth and activity of grasses improves soil aggregation, decreases soil bulk density and supplies large quantities of organic material to soils from roots. Cattle manure has been used as a soil amendment in agricultural systems for centuries. The addition of cattle manure to soil provides several potential benefits by improving soil structure, fertility and increasing soil organic matter (McAndrews *et al*. 2006). Because manure has a high organic matter content, the application of cattle manure also often helps restore depleted organic matter in degraded areas, and a majority of nutrients added through manure applications are in organic form (Zhang *et al*. 2006), which implies slow release over a longer period than is obtained from most inorganic fertilizers. The aim of this study was to investigate the relationship between soil compaction and properties of the vegetation on rehabilitated surface coal mined soil. This will clearly highlight to what extent the agricultural potential of the area is affected, especially the biomass yield available for animal production. This was achieved by evaluating an ameliorated compacted mined soil with cattle manure and planted to an indigenous pasture species used to reinstate the agricultural potential of rehabilitated land.

Methods

Field experiments were conducted with Smuts Fingergrass (*Digitaria eriantha* cv. Irene) a commonly used pasture for cattle production and indigenous species to the grassland biome. The experimental design was a complete randomized design with 5 treatments and 5 replications. Cattle manure incorporation rates of 0, 20, 40, 80 and 120 tons/ha were evaluated to establish the plant growth responses to this range of treatments. The ameliorated soil treatments were planted to Smuts Fingergrass. The gross plot dimensions for Smuts Fingergrass were 9 x 2 m with 25 plots in total.

The soil used was a uniform sandy clay loam soil belonging to the Hutton soil form (Soil Classification Working Group 1991) imported from a surface coal mine. After a series of wet and dry cycles all the cattle manure ameliorated soils were compacted while being placed to a depth of 60 cm, for an equivalent amount of time with a gentle vibration until a maximum mean soil strength of 2500 kPa had been reached for the control treatment. The 60 cm soil depth represents the depth at which soil is placed during the reclamation of an arable land capability class on a rehabilitated surface coal mine.

Penetrometers provide a quantitative measure of the soil's compaction. Vazquez *et al*. (1991) interpreted penetration resistance to be tenfold more sensitive than bulk density as an indicator of soil compaction (Landsberg *et al.* 2003). Soil penetration resistance was determined by using a static cone penetrometer, the Geotron, Model P5 hand penetrometer (Geotron, Potchefstroom, South Africa). This measures soil resistance to penetration (in kPa) of a steel cone of 12.8 mm diameter with 30° cone angle and cone base area of 130 mm². In this study, the level of compaction of the soil was determined by comparing the penetration resistance (PR) among the treatments. Atwell (1993) reports that penetration resistances greater than 2000 kPa generally produce significant reductions in root growth (Lampurlanés and Cantero-Martínez 2003). Therefore in this study, soil with a penetration resistance >2000 kPa was regarded as being compacted. The penetrometer was set to record at 1 cm intervals; from 0 to 65 cm at an insertion rate of 1000 mm/min at 1 second/rev. In this study, the soil moisture was at field capacity when the penetrometer measurements were taken. When water supply and nutrition are not limiting, soil strength (penetrateion resistance) determines the rate of root elongation (Whalley *et al.* 1995).

In addition to the soil physical properties measured including: aboveground biomass and below ground root mass of the pasture species. The above ground biomass was measured by clipping the plant material to 7 cm above the soil surface and then oven drying to provide the dry matter weight. Below ground biomass was measured by excavating a 0.9 cm^2 area around 10 randomly selected plants per plot to a 60 cm depth, washing and sieving out all the roots from this excavated soil profile, and dry and weighing the root material. These values were used to establish how soil compaction, soil amelioration with cattle manure correlates with biomass yields as determined by root development (mass).

Statistical Analysis

Data were analysed using one-way ANOVA followed by Tukey's Studentized Range Test ($p \geq 0.05$) together with PROC GLM using SAS software version 9.2 (SAS Institute Inc., Cary, NC).

Results

To re-establish the agricultural potential of a mined soil, it is imperative to have accurate measures of the yield of the crop grown thereon. The dry matter forage yield data collected from this research trial, illustrated the significant influence of different levels of cattle manure *i.e.* 0, 20, 40, 80 and 120 tons/ha had on the yield of Smuts Fingergrass grown on rehabilitated mine soil (Fig. 1). The linear relationship between the different treatments can be seen, however, it is noted that after the first growing season a threshold has been reached and that there are no significant differences between the amelioration rates of 40 and 120 tons/ha. This can possibly be ascribed to the fact that the amount of nutrients required for the growth of Smuts Fingergrass, is sufficient in the 40 tons/ha application rate, and that any excess cattle manure provided will not necessarily be used as a nutrient source. This requires further investigation and justification especially in relation to the effects of manure rate over time. It is equally important to recognize the physical amelioration effect of

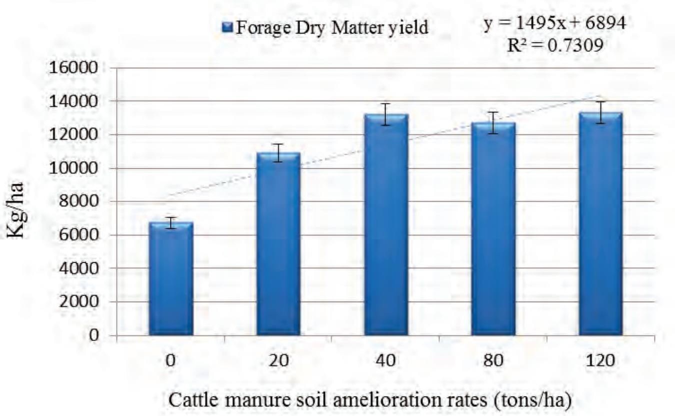

Figure 1. Influence of different treatment levels of cattle manure on the forage dry matter yields of Smuts Fingergrass (*Digitaria eriantha* cv. Irene).

cattle manure on soil structure, thereby mitigating the soil compaction of the structureless soil resulting from the excavation process prior to mining once placed back during the rehabilitation of the mined land.

It is evident from the rorrelation between root biomass and soil strength (Fig. 2) that the higher levels of cattle manure had a significant effect on root development of the Smuts Fingergrass. To illiustrate this highly significant relationship between the root biomass of Smuts Fingergrass and soil strength of compacted soil amended with different levels of cattle manure, only the 0, 40 and 80 tons/ha treatments were evaluated. The highest mean root biomass of Smuts Fingergrass was observed for soil receiving ~80 tons/ha of cattle manure, followed by the 40 tons/ha treatments, with the lowest yield measured in the untreated control. The decrease in soil strength with increasing rates of cattle manure application was due in part to an increase in root mass (Fig. 2). Improvements in soil aeration and soil structure reflect an increase in soil organic matter content which is attributed to both grass roots and the applied organic cattle manure. These results are supported by work conducted by Li *et al.* (2007) who found a direct relationship between the changes in bulk density and water holding capacity as a function of net increases in soil organic carbon caused by organic waste applications. Similarly, Hati *et al.* (2007) reported a reduction in the bulk density of the soil and higher root mass of both soybean and wheat due to the application of farmyard manure.

Conclusion

Compaction which increases soil strength has a negative effect on plant growth and prevents successful re-vegetation and rehabilitation of opencast mined lands. Following this investigations, it can be concluded that the amelioration of a structureless mined soil with an organic material such as cattle manure at a rate of about 40 tons/ha can facilitate plant growth in these soils. Combining organic matter inputs with an the sowing of an adapted indigenous pasture species such as Smuts Fingergrass, will effectively mitigate the compaction of mined soil and should therefore for part of any mine rehabilitation process. A mean soil strength reduction of 1000 kPa was achieved by using cattle manure as a soil ameliorant to enhance the growth of an indigenous pasture species. It can therefore, also be concluded that cattle manure provides sufficient nutrients and organic matter to enhance the soil physical properties sufficient to achieve good root development to ensure good forage production for animal production. This improved forage dry matter production on rehabilitated soils will increase the agricultural potential of a rehabilitated mined area.

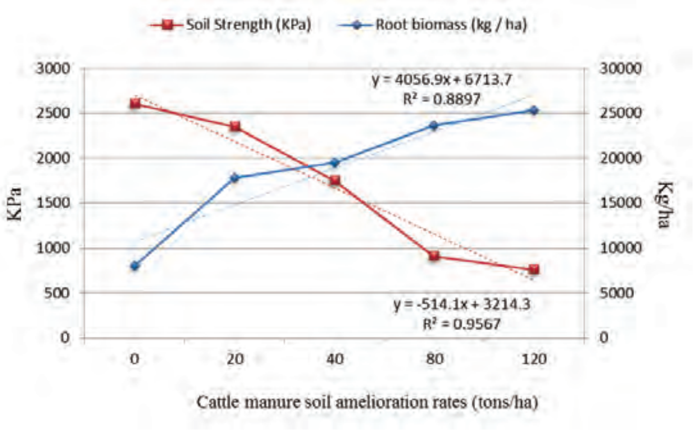

Figure 2. Relationship between soil strength and root biomass of Smuts Fingergrass (*Digitaria eriantha* cv. Irene) grown on compacted mine soil amended with different levels of cattle manure.

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