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Baseline status of microbial activity on gold tailings facilities in South Africa

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ABSTRACT

In many ways, South Africa's landscape has been dominated by mining, given that, for so many years this sector has been the mainstay of the South African economy. As such the environmental impacts of these mining activities are one of the greatest globally. These environmental impacts need to be addressed during each phase of environmental planning, especially during mine closure. By investigating the microbial enzymatic activity of tailings associated with different gold mine waste disposal environments in order to distinguish the effects of gold mining on associated ecosystems. This research will exemplify the importance of microbiological enzymatic characteristics as part of rehabilitation assessment criteria. Soil enzymatic and physicochemical analysis were analysed by standard methods and the result emphasised that the tailings materials possess poor microbial enzymatic activities. The baseline soil microbial activity levels of the tailings are dependent on the specific chemical, physical and biological parameters of the tailings materials. The microbial activity of the different gold tailings storage facilities varied greatly. Generally, the microbial enzymatic activity was greater on the surface/rhizosphere zone in the partially revegetated tailings sites. In contrast, the barren tailings had the lowest microbial enzymatic activity, which also had the lowest acidic pH. The low dehydrogenase, β-glucosidase, urease, acid and alkaline phosphatase enzymatic activities observed at these mining sites signifies that tailings materials possess poor microbiological enzymatic characteristics. Consequently, it can be assumed that the soil quality and fertility of these sites are lower because of decreased microbial activity due to the deficit of biodegradable organic matter and limited nutrient cycling. The mine waste disposal environment is devoid of true soil character deprived of macro and micro-nutrients, acidic pH with elevated concentrations of trace metals. Thus, indicating a high degree of soil degradation and poor soil health that affects not only the chemical and physical characteristic of the tailings material but also the microbiological properties. As such, it is clear that the contribution that microbes make to the ecosystems functioning in extreme environments, such as mine waste disposal environments is vastly underrated. Subsequently, microbial processes need to be included into mine rehabilitation practices, hypotheses, models, and interpretation of rehabilitation findings. To conclude, the study provided a microbial baseline status of different gold tailings storage facilities that will provide a platform for future investigations.

1. Conceptualisation

The concept of baseline status of a specific study or project is to make use of known data or values which could be used for comparison purposes. It is essential to establish the baseline status in relative new research projects where there is not a lot of information available. In research projects where variations or improvement of the qualitative data is present, it is even more relevant to establish the baseline status. Although baseline data in natural sciences are absolute data, it is used rather in a relative sense with further research data. There are numerous datasets individually for soils, microbial activity and less for mine tailings and even much less for gold tailings specifically as microbial activity in gold mine tailings is not a very common topic of discussion in natural sciences. The focus of this report and data discussion is to establish a baseline status and starting point for soil microbial activity in gold tailings.

1.1. Introduction

In South Africa, mine tailings are synonymous with environmental contamination, erosion and difficult to rehabilitate. These mine tailings have various constraints that prevent successful rehabilitation such as low nutrient status, poor physical structure, extremely acidic pH, in most cases very saline and last but not the least a major deficiency in

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soil microbial activity. Poor physical, chemical, and biological characteristics are responsible for very hostile conditions and in total a very low soil quality status. Without the appropriate rehabilitation, mine tailings are considered to be a hostile environment for the establishment of plants and soil organisms. Soil organisms positively contribute to the modification of soil structure, creating new ecosystems and contribute mainly to germination, root development, and many other plants physiological activities. As the result of poor mine rehabilitation performances in South Africa, not one single gold mine tailings dam received a mine closure certificate according to Section 28(1) of the MPRDA, 2002 regulations. Difficulties arise from the fact that several government departments are involved in environmental closure (e.g., Department of Mineral Resources (DMR), Department of Water Affairs (DWA) and Department of Environmental Affairs (DEA)), as well as insufficient successful legal closure applications (Milaras et al., 2014). More distressing is the fact that South Africa has around five thousand ownerless and derelict mines (Department of Minerals and Energy (DME), 2007).

1.2. Background

Abandoned pyrite-rich gold tailings storage facilities (TSF) pose numerous threats to the environment and requires rehabilitation according to legislation. In the South-African rehabilitation industry, the establishment of vegetation is a common practice. The primary aim of mine rehabilitation is to create surface stability and secondary to restore and re-establish a sustainable functional ecosystem. One of the key challenges in mine rehabilitation is the successful establishment of a self-sustaining vegetative cover on the tailings storage facilities and disturbed areas. Presently, the standards for successful mine rehabilitation has mainly been constrained to physicochemical status, soil erosion and vegetation physiognomies. These environmental stresses induce profound changes and disrupting the functional stability of the microbial community. The criteria used to determine successful rehabilitation requires the integration of ecological principles; as rehabilitation approaches using narrow criteria sets of vegetation species selection criteria or definite chemical parameters that have been proven to be inadequate. Microorganisms have an effect on most of the criteria that are used to determine rehabilitation success, yet they are not specifically included in any of them. It is widely known that microbial communities control essential ecosystem processes, yet microorganisms largely remain unrecognised in mine reclamation and rehabilitation. Microorganisms mediate important ecosystem functions in the soil and thus the recovery of the soil microbial community is a critical step in achieving the goal of sustainable and beneficial tailings restoration. In order to get a comprehensive understanding of mine waste disposal environments and its rehabilitation microbial processes need to be included in hypotheses, models, and interpretation of findings.

1.3. Research question and motivation

Poor vegetation cover on rehabilitation of gold mine tailings and a lack of biological norms and standards put question marks behind current practices and specifications. A major lack of available literature on soil quality and specifically soil microbial activity on gold mines that have been rehabilitated, also contribute to the ambiguous specifications of rehabilitation projects.

Questions that evolved from the above mentioned are the following:

- What are the role, purpose and activity of soil health in mine rehabilitation?
- To what extent does soil microbial activity contribute to soil health in mine rehabilitation?
- Is it possible to distinguish between microbial activity in natural soils and anthropogenic mine soils?
- Is there a difference in soil microbial activity between different anthropogenic mine soils?
- Lastly, is it really worth it to spend time and resources on microbial activity investigations and research relating to soil health in mine tailings rehabilitation?

1.4. Aims and objectives

This paper will outline the baseline status of microbial activity of a few gold tailings storage facilities and compare it to natural soils and to a limited extend to other types of mine tailings. It will also emphasise the importance of quantifying soil microbial activity. This paper is part of a larger research project which is undertaken to differentiate the soil health of different tailings materials and to develop a framework to improve soil microbial activity and soil quality in mine rehabilitation.

The objectives of this paper could be summarised as follows:

- Determine the standard soil health by evaluating the soil microbial enzymatic activity of some gold mines and some other mine tailings,
- Compare the data with data from natural soils,
- Demonstrate the degree of degradation present of different tailing facilities,
- Ultimately demonstrate the importance of microorganisms as a factor that needs to be taken into consideration when rehabilitating mine waste environments.

Emphasis is placed on the differential differences in soil dehydrogenase activity on the gold mines TSF's, and to relate the microbial activities to the physical and chemical conditions of the tailings, as well as the performance level of revegetation projects.

2. Literature study

It is necessary to know the mine waste research environment in order to get a better understanding and background on mine rehabilitation and specifically on soil health and microbial activity. Therefore, mine tailings characteristics, the comparison between anthropogenic mine soils and natural soils and microbial activity in these two mediums are discussed briefly.

2.1. Mine waste characterisation

South Africa is considered one of the most important mining countries in the world and produces large amounts of mine waste. Mine waste generation at different mines varies considerably in their properties due to distinctive mining and extraction techniques used, and the differences in the mineralogical composition of the mined ore/rock. Mine waste can be divided into two groups: 1) Mine tailings, generated when processing the ore and 2) waste rock produced when uncovering the ore body (Ledin and Pedersen, 1996; Lottermoser, 2010; Dold, 2010). Mine tailings are generally considered an environmental threat due to their impacts on air quality, groundwater quality, aesthetics and land use (Ritcey, 1989; Plumlee and Morman, 2011). The physical, chemical, mineralogical and microbiological aspects of the tailings will determine its impact on ecosystem functioning and stability (Ledin and Pedersen, 1996). Waste generation is a side effect of consumption and production activities within the mining industry and tends to increase with economic advancement. During the mining and processing of sulphide-rich ore bodies, large quantities of overburden mine-waste are generated. These materials are often a major source of trace metal and salt pollution in the local environment, due to wind erosion (dust) and potential leaching of the products of mineral weathering into a water source. The acidic mine waste contains large amounts of iron sulphide minerals, such as pyrite and pyrrhotite (Dold, 2010). The exposed TSF's oxidises the pyrite-containing tailings materials undergoing oxidation and forming sulphuric acid, resulting in a highly acidic environment. Under these acidic conditions, the metal sulphides react to the sulphuric