MODELLING LEAD AND CADMIUM UPTAKE BY STAR GRASS UNDER IRRIGATION WITH TREATED WASTEWATER

BY

SIMON MADYIWA

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ABSTRACT

MODELLING LEAD AND CADMIUM UPTAKE BY STAR GRASS UNDER IRRIGATION WITH TREATED WASTEWATER

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Simon Madyiwa

Supervisor	:	Professor C. F. Schutte
Department	:	Chemical Engineering
Degree	:	Philosophiae Doctor

This study was conducted to investigate the capacity of *Cynodon nlemfuensis* (star grass) to accumulate lead (Pb) and cadmium (Cd) and develop metal uptake models for sandy soils receiving treated sewage from domestic and industrial sources. The study area comprised a non-polluted area and an adjacent area that received treated sewage from Harare's Firle Wastewater Treatment Plant for over 30 years.

Measured soil properties, total Pb and Cd in soils and grass and past records of Pb and Cd in treated sewage were analysed. Growing grass in a greenhouse in pots with previously non-polluted soils amended by single and mixed Pb and Cd salts and irrigated with treated sewage tested the uptake capacity of star grass. Yields, soil bio-available and grass Pb and Cd levels were measured and used to develop models for estimating critical soil and grass concentrations at which productivity declines. In the field, star grass grown in 10m x 10m plots in the non-irrigated and irrigated areas, received varying amounts of treated sewage over 11 months. Soil bio-available and grass metal contents were measured and used to develop field-based models to predict Pb and Cd content in star grass.

Star grass had a high Pb and Cd extraction capacity, making it unsuitable for pasture if grown on polluted soils. Correlation between total Pb and Cd in soils and grass was insignificant ($p<0.05$). Logarithm-based models of $\log_{10}$ *bio-available soil levels* and $\log_{10}$ *grass metal levels* provided the best-fit regression models for Pb and Cd predictions in grass. Toxicity levels of Pb and Cd that were derived for star grass from pot-based models were higher than levels recommended for pasture. Toxicity occurred without visible signs on grass, making it difficult to recognise toxicity without testing. The field-based uptake models predicted safe bio-available limits for pasture on sandy soils. The co-presence of Pb and Cd resulted in increased Cd uptake but did not significantly affect Pb uptake. Star grass can accumulate more than 1 mg/kg of Cd at total soil Cd levels of less than 1 mg/kg, suggesting that the soil limit may be too high for a sandy soil.

Key words: Modelling Pb and Cd; *Cynodon nlemfuensis*; Sandy soil; Treated sewage

EXECUTIVE SUMMARY

MODELLING LEAD AND CADMIUM UPTAKE BY STAR GRASS UNDER IRRIGATION WITH TREATED WASTEWATER

Supervisor	**:**	Professor C. F. Schutte
Department	**:**	Chemical Engineering
University	**:**	University of Pretoria
Degree	**:**	Philosophiae Doctor

This study was conducted to investigate the capacity of *Cynodon nlemfuensis* (star grass) to accumulate lead (Pb) and cadmium (Cd) from a sandy soil irrigated with treated sewage. It also aimed to develop soil-vegetative tissue uptake models for predicting Pb and Cd levels in star grass using measured soil concentrations.

By growing star grass in pots with sandy soils amended using different levels of single and mixed inorganic salts of Pb and Cd and applying treated sewage, this study established that star grass is a high accumulator of Pb and Cd. It also established that the co-presence of Pb and Cd in the soil leads to increased uptake of Cd but does not significantly affect uptake of Pb by star grass. Star grass accumulated 8 times and 18 times the maximum levels of 40 mg/kg Pb and 1 mg/kg Cd recommended for pasture (United Kingdom Statutory Instrument No. 1412, 1995), respectively. The co-presence of Pb and Cd led to a 2.6-fold increase in uptake of Cd but did not significantly affect Pb bio-available soil levels and uptake by star grass.

Using the pot experiment, this study established that soil bio-available metal levels significantly ($p \leq 0.05$) correlate with plant metal levels through logarithm-based single-factor linear regression models of $\log_{10}$ (*above-ground tissue metal concentrations*) versus $\log_{10}$ (*soil bio-available metal concentrations*). The models predict toxicity in star grass to occur at 53.7 mg/kg Pb and 3.2 mg/kg Cd, corresponding to soil bio-available levels of 186.2 mg/kg Pb and 8.3 mg/kg Cd. Since toxicity occurred at metal levels higher than recommended for pasture without visible signs showing, the study recommends that visual signs of toxicity should not be used to decide when to stop grazing animals. Regular monitoring of bio-available levels of Pb and Cd is recommended.

In the field experiment where Pb and Cd levels in field plots were varied among treatments by applying different quantities of treated sewage, this study produced a significant ($p \leq 0.05$) model: $\log_{10}$ (*above-ground tissue Pb concentration*) = 0.3949$\log_{10}$ (*soil bio-available Pb concentration*) + 0.7880 for Pb and a strong (but marginally insignificant) model: $\log_{10}$ (*above-ground tissue Cd concentration*) = 0.363$\log_{10}$ (*soil bio-available Cd concentration*) + 0.2987 for Cd. The models predict that, to maintain Pb and Cd levels in star grass below recommended limits, soil bio-available levels should not exceed 115.2 mg/kg Pb and 0.20 mg/kg Cd. Therefore this study recommends management of soil bio-available Pb and Cd in sandy soils below 115.2 mg/kg and 0.20 mg/kg respectively, to ensure that star grass pasture is safe for animal consumption. The field-based models are considered suitable where animals graze regularly, facilitating re-growth of star grass over time.

Other results from this study suggest that the recommended limit of 1 mg/kg total Cd in soils may be too high for sandy soils under repeated disposal of treated sewage. In this study, some samples of mixed kikuyu and star grass from a sandy soil exposed to 29 years of treated sewage disposal tested up to 1.2 mg/kg despite the soil having a total Cd of 0.65 mg/kg.

THESIS CONTRIBUTION TO KNOWLEDGE

A comparison of the capacity of the *Cynodon nlemfuensis* (star grass) to accumulate Pb and Cd, obtained from this study, and that of other plants contributes vital information towards the search for hyper-accumulators. By absorbing 4 592 mg/kg Pb, star grass ranks as a strong Pb accumulator among grasses, considering that hyper-accumulating grasses such as *Lolium perenne* (rye grass) accumulated 5 390 mg/kg Pb (US Department of Energy, 1998). However overall, star grass ranks as a medium accumulator of Pb when compared to hyper-accumulating plants such as Ipomea which accumulated 15 000 mg/kg in shoot tissue (Rhyne and Gosh, 2002). Given that grasses within a species have similar uptake characteristics (McDonald et al., 1995), these findings suggest that the *Cynodon* species of grasses has uptake capacities close to 4 592 mg/kg, accompanied by very low yields. This implies that the *Cynodon* species may be a medium Pb extractor whose use in phyto-remedying polluted soils may be limited.

Prior to this study, Pb and Cd uptake characteristics that are critical to the growth and monitoring of suitability of star grass pasture, growing on soils polluted with Pb and Cd were not known. No known models were available for estimating Pb and Cd levels in star grass growing on sandy soils on which treated sewage is disposed. This study contributed to the development of soil-plant metal uptake models by combining the use of bio-available concentrations in soils and the concept of log-transforming soil and metal concentrations in grass to produce single-factor regression models for estimating Pb and Cd levels in grass based on bio-available soil levels. Using the models, the study estimates that toxicity of Pb and Cd in star grass occurs at 53.7 mg/kg Pb and 3.2 mg/kg Cd corresponding to critical soil bio-available levels (extracted using 1 M ammonium acetate) of 186.2 mg/kg Pb and 8.3 mg/kg Cd.

Furthermore, the study provides an indication of the critical levels of soil concentrations that should not be exceeded in order to ensure that levels in star grass are below recommended maximum levels. Using regression models:

(1) $\log_{10}$ (*above-ground tissue Pb concentration*) = $0.3949\log_{10}$ (*soil bio-available Pb concentration*) + 0.7880

(2) and $\log_{10}$ (*above-ground tissue Cd concentration*) = $0.363\log_{10}$ (*soil bio-available Cd concentration*) + 0.2987,

developed under field conditions, the study estimated that soil bio-available levels should be maintained below 115.2 mg/kg Pb and 0.20 mg/kg Cd to ensure compliance of star grass metal content with recommended limits of 40 mg/kg Pb and 1 g/kg Cd (United Kingdom Statutory Instrument No. 1412, 1995) for pasture grass.

Literature presents what appears to be conflicting evidence on the influence of Pb on Cd and *vice versa* on uptake by plants. By assessing the effect of the co-presence of Pb and Cd in the soil on uptake of the metals by star grass, this study contributes towards increasing available information on interactions of the metals in plants. This study found that the addition of Pb and Cd to the soil increased uptake of Cd 2.6-fold over uptake observed with single metals added to the soil, while uptake of Pb was not affected significantly in star grass. Therefore available information on interactions of Pb and Cd may not be conflicting but an indication of different uptake characteristics of plants. It may also be argued that besides reducing Cd levels in treated sewage, reduction of Pb levels can contribute towards reducing uptake of Cd.

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