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

BY

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ABSTRACT

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

by

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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

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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: $\log_{10}(\text{above-ground tissue Pb concentration}) = 0.3949 \log_{10}(\text{soil bio-available Pb concentration}) + 0.7880$ for Pb and a strong (but marginally insignificant) model: $\log_{10}(\text{above-ground tissue Cd concentration}) = 0.363 \log_{10}(\text{soil bio-available Cd concentration}) + 0.2987$ 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) $\log_{10} (\text{above-ground tissue Pb concentration}) = 0.3949 \log_{10} (\text{soil bio-available Pb concentration}) + 0.7880$
- (2) and $\log_{10} (\text{above-ground tissue Cd concentration}) = 0.363 \log_{10} (\text{soil bio-available Cd concentration}) + 0.2987,$

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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TABLE OF CONTENTS

CHAPTER	PAGE
EXECUTIVE SUMMARY	i
THESIS CONTRIBUTION TO KNOWLEDGE	iii
ACKNOWLEDGEMENT	v
1.0 INTRODUCTION	1
1.1 Environmental and human health concerns of Pb and Cd	1
1.2 Metal pollution from wastewater	1
1.3 Paucity of data on accumulation of Pb and Cd in star grass	2
1.4 Challenges in modelling plant metal uptake from soils	3
1.4.1 Soil metal concentrations and sampling depth	4
1.4.2 Differences in uptake characteristics of plants	4
1.4.3 Influence of uptake by other metals	5
1.5 Objectives of study	6
1.6 Scope of study	6
1.7 Organisation of thesis	7
2.0 LITERATURE REVIEW	9
2.1 Essential and non-essential heavy metals for plants	9
2.2 Sources of Pb and Cd	9
2.2.1 Lead	10
2.2.2 Cadmium	10
2.3 Treated wastewater as source of Pb and Cd	11
2.4 Chemistry of Pb and Cd	13
2.4.1 Lead	13
2.4.2 Cadmium	13
2.5 Metal contamination and toxicity	14
2.5.1 Lead	16
2.5.2 Cadmium	16
2.6 Bio-availability of heavy metals	17
2.7 Lead and cadmium health hazards to humans	18

2.8	Plants as soil cleaners and pathway of Pb and Cd to food chain	19
2.9	Treated sewage as source of Pb and Cd hazard to grazing animals via plants	20
2.10	Potential of grasses to accumulate Pb and Cd	21
2.11	<i>Cynodon nlemfuensis</i>	21
2.12	Reliability of standard permissible toxic metal guidelines	22
2.13	Reliability of guidelines of loading rates for wastewater on soils	23
2.14	On land sewage disposal methods	26
2.15	Influence of plant and other chemical species on metal uptake	26
2.16	Models for heavy metal content prediction	27
	2.16.1 Mass balance approach	27
	2.16.2 Use of soil-plant system models for metal prediction	28
2.17	Metal uptake in sewage amended soils	30
2.18	Review of methods of measuring bio-available metal concentrations	30
2.19	Review of some findings of pot and field methods for determining metal Uptake	32
2.20	Review of sewage treatment systems in Zimbabwe	33
2.21	Problem statement and hypotheses	35
	2.21.1 Problem statement	35
	2.21.2 Potential benefits of study	36
	2.21.3 Hypotheses	37
3.0	METHODOLOGY	38
3.1	Introduction	38
3.2	Background of study area	38
	3.2.1 Location of study area	39
	3.2.2 Sources of pollutants for study area	40
	3.2.3 Treatment plants	41
3.3	Study design	41
	3.3.1 Baseline assessment of Pb and Cd levels in study area	43
	3.3.2 Greenhouse Pb and Cd uptake by star grass under treated sewage application	45
	3.3.3 Field assessment of Pb and Cd uptake	47

3.3.4	Data analysis	48
4.0	BASELINE ASSESSMENT OF LEAD AND CADMIUM LEVELS IN STUDY AREA	51
4.1	Introduction	51
4.2	Objectives	51
4.3	Detailed methods and materials	51
4.3.1	Analysis of past records on levels Pb and Cd in treated sewage	51
4.3.2	Baseline assessment of chemical characteristics of study area	52
4.4	Results	54
4.4.1	Analysis of past records on levels of Pb and Cd in treated sewage	54
4.4.2	Chemical characteristics of study area	55
4.5	Discussion	59
4.5.1	Analysis of past records on levels of Pb and Cd in treated sewage	59
4.5.2	Pb and Cd accumulation in soils and grasses	60
4.5.3	Implications of findings	63
5.0	ASSESSMENT OF LEAD AND CADMIUM UPTAKE BY <i>Cynodon nlemfuensis</i> UNDER REPEATED APPLICATION OF TREATED WATER	66
5.1	Introduction	66
5.2	Objectives	67
5.3	Detailed methods and materials	67
5.3.1	Experimental set-up	67
5.3.2	Grass establishment	68
5.3.3	Soil treatment and irrigation application	69
5.3.4	Soil sampling and testing	70
5.3.5	Grass sampling and testing	70
5.3.6	Sewage effluent and sludge collection and testing	70
5.3.7	Data analysis	71

5.4 Results	72
5.4.1 Bio-available Pb and Cd content of soils	72
5.4.2 Extraction capacity of star grass	73
5.4.3 Grass metal content response to bio-available soil metal content in single treatments	73
5.4.4 Yield response to Pb and Cd content of grass in single treatments	75
5.4.5 Interactions of Pb and Cd in mixed treatments	78
5.4.6 Correlations of Pb and Cd in grass	82
5.4.7 Yield response to combined Pb and Cd	82
5.4.8 Yield, grass and soil metal content models and critical limits of Pb and Cd	84
5.4.9 Pb and Cd levels in effluent and sludge mixture	87
5.5 Discussion	87
5.5.1 Extraction capacity of star grass	87
5.5.2 Grass yield response to Pb and Cd	89
5.5.3 Metal uptake models and critical metal limits	89
5.5.4 Implications of findings	93
6.0 FIELD ASSESSMENT OF LEAD AND CADMIUM UPTAKE BY <i>Cynodon nlemfuensis</i> UNDER REPEATED APPLICATION OF TREATED WASTEWATER	94
6.1 Introduction	94
6.2 Objectives	95
6.3 Detailed methods and materials	95
6.3.1 Estimated irrigation requirements of star grass	95
6.3.2 Experimental set-up	96
6.3.3 Preparation of field plots	97
6.3.4 Irrigation of grass	98
6.3.5 Soil sampling and testing	99
6.3.6 Grass sampling and testing	100
6.3.7 Sewage effluent and sludge sampling and testing	100
6.3.8 Data analysis	100
6.4 Results	101

6.4.1	Soil pH, cation exchange capacity and clay content	101
6.4.2	Bio-available Pb and Cd content of soils and grass	103
6.4.3	Soil bio-available Pb and Cd response to treatment	106
6.4.4	Grass Pb and Cd content response to treatment	107
6.4.5	Correlations between bio-available and grass Pb and Cd contents for each grass crop	108
6.4.6	Correlation between average bio-available Pb and Cd in soils and average Pb and Cd contents in grass	110
6.4.7	Rate of metal application from treated sewage	112
6.5	Discussion	113
7.0	GENERAL DISCUSSION	116
7.1	Long-term Pb and Cd accumulation in soils and bio-available levels	116
7.2	Capacity of star grass to absorb Pb and Cd	117
7.3	Yield responses to increasing bio-available Pb and Cd	118
7.4	Yield-metal uptake models for Pb and Cd and toxic limits in grass	118
7.5	Soil bio-available-grass metal uptake models and critical metal limits	118
7.6	Co-presence of Pb and Cd	120
7.7	Appropriate Pb and Cd levels in effluent and digested sludge	120
8.0	CONCLUSIONS AND RECOMMENDATIONS	122
8.1	Main conclusions	122
8.2	Recommendations	125
TABLES		
Table 2.1	Sewage type, loading rates and soil type (Source: Chatterjee, 1987)	24
Table 2.2	German standards for heavy metals in soil and sludge (Pescod et al, 1985)	24
Table 2.3	Recommended maximum concentrations of trace elements in irrigation Water (adapted from Pescod, 1992)	25
Table 4.1	Average (range) concentration (mg/l) of heavy metals in samples	

	of digested sludge and effluent (Source: Harare City Council records, 1991-1994)	55
Table 4.2	Selected properties of a sandy soil in the irrigated and control areas	56
Table 4.3	Average total soil metal concentrations in horizons of soil profile of the irrigated and control areas	57
Table 4.4	Average total metal levels (mg/kg) in 0-20cm soil depth and mixed grass	58
Table 5.1	Soil metal and grass concentrations, yields and metal extraction levels	74
Table 5.2	Pb concentrations in samples of treated effluent and sludge mixture	87
Table 6.1	Estimated crop water and irrigation requirements of star grass	96
Table 6.2	Mean soil properties and soil depth	102
Table 6.3	Correlation coefficients for pH, cation exchange capacity and clay content versus soil depth	103
Table 6.4	Mean soil profile bio-available metal and grass concentrations	104
Table 6.5	Correlation coefficients for soil depth and bio-available soil metal concentration	105
Table 6.6	Average bio-available Pb and Cd levels in soils and grass (mg/kg)	106
Table 6.7	Quantities of treated sewage and computed average metal concentrations applied to plots	112
Table 6.8	Average increase in profile Pb and Cd levels above levels in the control (mg/kg)	113

LIST OF FIGURES

Figure 2.1	Generalised dose-response curve for nutrient metals	15
Figure 3.1	Schematic diagram of study area	39
Figure 5.1	Log ₁₀ soil bio-available level versus log ₁₀ Pb level in grass in single treatments	75
Figure 5.2	Log ₁₀ bio-available Cd level versus log ₁₀ Cd levels in grass in single treatments	76
Figure 5.3	Log ₁₀ Pb level (mg/kg) in grass versus log ₁₀ grass yield (g/pot)	

	in Pb single treatments	77
Figure 5.4	Log ₁₀ Cd level (mg/kg) in grass versus log ₁₀ yield of grass (g/pot) in single Cd treatments	78
Figure 5.5	Effect of treatment on bio-available levels of Pb in single and mixed treatments	79
Figure 5.6	Effect of treatment on levels of Pb in grass in single and mixed treatments	80
Figure 5.7	Log ₁₀ bio-available soil Pb levels (mg/kg) versus log ₁₀ Pb levels in grass re-growth (mg/kg) in mixed treatments	80
Figure 5.8	Effect of treatment on bio-available levels of Cd in single and mixed treatments	81
Figure 5.9	Effect of treatment on bio-available Cd levels in grass in single and mixed treatments	81
Figure 5.10	Log ₁₀ bio-available Cd soil levels (mg/kg) versus log ₁₀ Cd levels in grass re-growth in mixed treatments	82
Figure 5.11	Correlation of metal contents of Pb and Cd in grass in single and mixed treatments	83
Figure 5.12	Yield response to concentrations of Pb and Cd in mixed Pb and Cd treatments	83
Figure 6.1	Plot layout at Churu farm	98
Figure 6.2	Treatment versus log ₁₀ bio-available soil Pb concentration	106
Figure 6.3	Treatment versus log ₁₀ bio-available Cd soil concentration	106
Figure 6.4	Treatment versus log ₁₀ grass Pb concentration	107
Figure 6.5	Treatment versus log ₁₀ grass Cd concentration	108
Figure 6.6	Log ₁₀ bio-available soil Pb versus log ₁₀ Pb level in grass in field experiment	109
Figure 6.7	Log ₁₀ bio-available soil Cd level versus log ₁₀ Cd level in grass	110
Figure 6.8	Log ₁₀ mean bio-available soil Pb versus log ₁₀ mean Pb level in grass	110
Figure 6.9	Log ₁₀ mean bio-available soil Cd versus log ₁₀ mean Cd level in grass	111

LIST OF REFERENCES **127**

APPENDICES

Appendix 1	Sewage treatment processes at Firlle Wastewater Treatment Plant	135
Appendix 2	Randomised block design layout of pots in greenhouse	137
Appendix 3	Quantities of treated sewage and metals applied to field plots	138
Appendix 4	Mean soil bio-available concentrations (standard deviations), mg/kg and soil depth	140