CHAPTER 7

GENERAL DISCUSSION

This chapter discusses the results obtained from all the components of the study, bearing in mind the main areas in which the study was focused. The major findings are as follows.

7.1 Long-term Pb and Cd accumulation in soils

The study found that after 29 years of disposal of treated sewage, Pb and Cd accumulation in the sandy soils occurred predominantly in the top 20 cm, particularly the top 10 cm of the soil. This is confirmed by the large difference in metal accumulation between the top and lower layers of the soil and similarity of metal levels in lower layers of irrigated and non-irrigated soils. This outcome was largely expected since organic matter, which concentrates in the top soil, has a high affinity for metals (McGrath and Lane, 1989).

At a total soil metal concentration of 186.3 mg/kg in the top 0-10 cm horizon and 33.3 mg/kg in the 10-20 cm horizon, long-term accumulation of Pb was largely below the recommended limit of 300 mg/kg in all horizons, suggesting that Pb was unlikely to be a hazard. This is confirmed by the fact that after 29 years of disposal of treated sewage on soils, mixed kikuyu and star grasses only absorbed a maximum of 1.5 mg/kg Pb. In addition, results from the field experiment show that star grass accumulated 15.33 mg/kg Pb, a figure lower than 40 mg/kg recommended for pasture grass and 53.70 mg/kg toxic limit obtained from the pot experiment. At an average annual accumulation of 5.7 mg/kg and sewage disposal regime similar to the previous 29 years, it would take another 20 years for Pb in the top 10 cm depth to reach the 300 mg/kg total Pb limit. This implies a longer period of disposal.

At 1.26 mg/kg in the 0-10 cm horizon and 0.75 mg/kg in the 10-20 cm horizon, total Cd exceeded the recommended 1 mg/kg in the top 10cm and was just below the limit in the 10-20 cm depth. This outcome suggested that Cd hazard was likely and is confirmed by uptake of up to 1.2 g/kg by mixed star and kikuyu grasses and 1.70 mg/kg by star grass in the field experiment.

The variation of metal levels with soil depth observed on total concentrations was also observed on bio-available levels in pots. The same trend was observed in the field. In all cases, this trend is attributed to the high affinity of organic matter for metals (McGrath and Lane, 1989). The variation of bio-available metal concentration with soil depth presents a potentially large source of error in relating soil concentrations to plant concentrations and in modelling soil-plant uptake. The depth interval at which various plants in different environments obtain water and nutrients and the relative biomass of feeder roots at different depths are unknown (US Department of Energy, 1998). Therefore, although the full 40 cm profile was assumed to be the depth from which grass roots took up nutrients as well as Pb and Cd in this study, this area may need further investigations.

7.2 Capacity of star grass to absorb Pb and Cd

A major feature of this study was to establish the capacity of star grass to take up Pb and Cd, given that the grass is grown for pasture and is irrigated using treated wastewater. In this respect the study found star grass to be a medium Pb and Cd extractor among plants, in general, and a high accumulator among grasses. In the pot experiment, it was capable of taking up as much as 4 592 mg/kg Pb and 316 mg Pb in the first crop and re-growth respectively and 16 mg/kg Cd and 18 mg/kg Cd in the first crop and re-growth respectively, in aerial plant parts. Severely retardation of growth at 4 592 mg/kg implies that this level was close to the maximum uptake capacity of star grass. Given that grasses within a species are known to have similar uptake characteristics (McDonald, 1995) the findings suggest that the *Cynodon* species of grasses possibly had a maximum Pb uptake capacity close to 4 592 mg/kg, implying that the *Cynodon* species may be a medium extractor of Pb. Phyto-extractors should combine high yields and high metal uptake (Baker et al, 2000). The absence of clear signs of growth retardation in Cd treatments in the greenhouse experiment suggests that the maximum extraction capacity of star grass was above 18 mg/kg attained in the experiment.

It should be noted that star grass was exposed to highly soluble Pb. High uptake of Pb is generally limited by insolubility of Pb in soils and hyper-accumulation occurs in contaminated soils when bio-availability is improved by chelates (McGrath et al, 2002). However, any unintentional contact between the grass in the first crop and added Pb during application of inorganic Pb may also have contributed to the large differences in levels between the first crop and re-growth in pot experiments. Using the results from re-growths, of from the pot study, star grass took up 8-fold and 18-fold the levels of 40 mg/kg and 1 mg/kg Cd recommended for pasture grass (United Kingdom Statutory Instrument No. 1412, 1995).

The lack of Pb and Cd toxicity signs at toxic concentrations suggests that animals could continue grazing on grass with Cd concentrations higher than the maximum limit of 1 mg/kg, unless the grass is tested or the soil is tested for bio-availability of the metal. This and the high extraction capacity of star grass imply that growing the grass for pasture in Pb and Cd polluted soils should be discouraged.

Despite total soil Cd being 0.65 mg/kg (35% lower than the 1 mg/kg maximum limit recommended for soils on which pasture grows), mixed kikuyu and star grasses accumulated up to 1.2 mg/kg Cd (20% more than the recommended limit in pasture grass). This outcome confirms the risk of relying on total soil metal concentrations when predicting hazard to animals. It also re-affirms the need to use bio-available soil metal levels instead of total concentrations in predictions. In the field experiment, star grass accumulated up to 1.70 mg/kg Cd, against a bio-available level of 0.63 mg/kg Cd (Table 6.4). Both results suggest that the limit of 1 mg/kg total Cd in the soil may be too high for star grass growing on a sandy soil under conditions of repeated application of treated sewage.

7.3 Yield responses to increasing bio-available Pb and Cd

Another key feature of this study was to examine relationships between soil bio-available levels and yield so as to predict the yield on the basis of soil bio-available concentration. The study found that the strength of this relationship was insignificant at 95% confidence level. There was very weak correlation between bio-available Pb and Cd and yield of star grass. Therefore, under the conditions of this study, $\log_{10}$ (*yield of above ground tissue*) versus $\log_{10}$ (*bio-available soil concentration*) of Pb and Cd models were not significant enough for accurate prediction of yield on the basis of soil bio-available concentrations. This implies that there were other factors not incorporated into these models, such as nutrients, that had influence on yield.

7.4 Yield-metal uptake models for Pb and Cd and toxic limits in grass

Single factor regression models for yield versus metal content in grass, based on $\log_{10}$ (*yield of above ground tissue*) and $\log_{10}$ (*metal concentration*) of Pb and Cd in the greenhouse experiment, were largely not significant ($p \leq 0.05$). Since Pb and Cd do not have known roles in metabolism, their effect below the toxic level is not clear but may be one of the reasons why the models are weak. Despite that, the models provide points where yield starts to decline allowing for estimation of the toxicity limit or toxicity threshold. The study estimated through dose-response models, that the toxic levels of Pb and Cd in star grass are 53.7 mg/kg and 3.2 mg/kg, respectively. It is further noted that these toxic levels of star grass are way above the recommended levels of Pb and Cd of 40 mg/kg and 1 mg/kg for pasture grass, respectively.

7.5 Soil bio-available-grass metal uptake models and critical metal limits

The development of soil-vegetative tissue metal uptake models on the basis of above-ground star grass tissue and soil bio-available metal concentration was another major feature of this study. Earlier findings confirmed that total soil metal levels were poorly correlated to metal concentrations in star grass. The best-fit models for soil bio-available and grass metal content data fitted into $\log_{10}$ function. Data from the greenhouse and field experiments fitted into this model, despite differences between the conditions under which the two experiments were conducted. Sample et al (1998) obtained significant model fits of ln (*total soil concentration*) and ln (*above ground plant concentrations*) using data from experiments carried out around the world.

The significant single variable regression models of $\log_{10}$ (*above-ground grass tissue Pb concentration*) = $0.525\log_{10}$ (*bio-available soil Pb concentration*) + 0.539 and $\log_{10}$ (*above-ground grass tissue Cd concentration*) = $0.451\log_{10}$ (*bio-available soil Cd concentration*) + 0.087 produced using single metals are considered suitable where single metals are added to the soil and for estimating toxicity limits. Bak and Jensen (1998) noted that eco-toxicity tests were often conducted on single metals. Therefore these models are not appropriate under field conditions, where other metals are also present in normal concentrations in the soil.

Under field conditions, the significant model $\log_{10}$ (*above-ground grass tissue Pb concentration*) = $0.395\log_{10}$ (*bio-available soil Pb concentration*) + 0.788, representing the average situation over 11 months, predicts the bio-available Pb level in soils to be 115.2 mg/kg for the recommended Pb limit in grass of 40 mg/kg. The model developed in the greenhouse predicts a bio-available Pb of 106.3 mg/kg for a limit of 40 mg/kg. This happens to be close to the value predicted in the field. Although the differences may be explained by the different conditions under which the 2 models were developed, the closeness of the two figures may be a result of the lack of influence of other metals on uptake of Pb, under experimental conditions

Under field conditions, none of the single variable regression models for Cd for individual crops was significant at 95% confidence level. This suggests that the numerous soil factors present under field conditions could have distorted the single variable relationship for each harvest. In that case, a multiple regression model could be more appropriate for Cd in the first crop and subsequent re-growths. The strength of the regression model for Cd under field conditions was vastly improved by treating each harvest as a replicate, with the resulting model falling just short of being significant. The model developed was $\log_{10}$ (*above-ground grass tissues concentration*) = $0.363\log_{10}$ (*bio-available soil concentration*) + 0.2987. This model predicts a soil bio-available Cd limit of 0.20 mg/kg as the concentration that would cause an accumulation of 1 mg/kg Cd in grass. This figure is different from the 0.65 mg/kg bio-available Cd predicted by the model $\log_{10}$ (*above-ground grass tissues concentration*) = $0.451\log_{10}$ (*bio-available soil concentration*) + 0.087, produced under greenhouse conditions. The differences are partly attributed to the different conditions under which the two models were developed and inadequate strength of the field-based model.

In general, it should be noted that under field conditions of this study, there were other factors that needed to be incorporated into the models to improve strength of Cd models. This may serve to explain the decline in the strength of correlation of both Pb and Cd with re-growths. US Department of Energy (1998) improved single variable regression models of natural $\log_{10}$ (*above-ground plant tissue concentration*) of Pb versus $\log_{10}$ (*total metal concentration in soils*) by incorporating pH in multiple regression models for Pb. Under the experimental conditions, the model, $\log_{10}$ (*above-ground grass tissues concentration*) = $0.363\log_{10}$ (*bio-available soil concentration*) + 0.2987, though not significant could be considered as indicative of the probable relationship between soil bio-available Cd and concentration of the metal in star grass under field conditions.

7.6 Co-presence of Pb and Cd

The results of this study suggest that co-presence of Pb and Cd does not significantly affect the levels of Pb in the sandy soil and star grass, a finding that is in agreement with what Carlson and Rolfe (1979) found in rye and fescue. The evidence is that there were no significant differences in the uptake of Pb in single and mixed treatments in the greenhouse experiment. The closeness in the predictions of bio-available Pb levels for a grass Pb content of 40 mg/kg between pot-based and field-based models is also consistent with this observation. Co-presence of Pb and Cd caused a 2.6 increase in the rate of uptake of Cd levels in star grass above the uptake in single treatments in the greenhouse experiment. It is therefore postulated that, besides the high levels of Cd in the treated sewage, co-presence of Cd and Pb contributed to the high uptake of Cd under field conditions.

7.7 Appropriate Pb and Cd levels in effluent and digested sludge

One of the objectives of this study was to determine appropriate levels of Pb and Cd in treated sewage to apply on pasturelands. Using the data obtained in this study it was not possible to determine appropriate levels in treated sewage since the levels of metals in the wastewater could not be varied. However some indications were derived from the data obtained in the study.

The levels of Pb and Cd in treated sewage fluctuated considerably. Pb in treated sewage was below legislated levels. The average Pb levels of 2.6 mg/l in digested sludge and 0.2 mg/l in effluent (Table 4.1), 1.2 mg/l determined during the greenhouse experiment and 0.4 mg/l determined during field experiment were all below the limit of 5.0 mg/l recommended for irrigation water (Ayers and Westcot, 1985). Therefore the low levels of Pb accumulation in grasses can partly be attributed the low levels in treated sewage.

In contrast to Pb, the average Cd level of 0.17 mg/kg in treated sewage applied during the field experiment, was above legislated limits, while the levels applied in the greenhouse experiment were generally below. The excessive Cd levels in treated sewage amounting to 0.17 mg/l (17 times the recommended long-term limit of 0.01 mg/l) appears to have been the determinant factor in causing high accumulation of Cd in grass. Therefore the uptake of Cd to levels higher than the recommended limits within a period of only 160 days after planting grass can be partly attributed to the high concentrations in treated sewage during the field experiment. This outcome suggests that the use of volume-based loading rates for deciding the application rate on a sandy soils and star grass would be of limited applicability unless the concentration of the metal is known. It also implies that even in the presence of organic matter, which is expected to immobilise Cd, bio-availability of Cd is still high. Doyle (1978) noted that Cd adsorbed by organic matter largely remained available for plant uptake. Mengel and Kirkby (1982) observed that Cd is readily transported to upper parts of plants leading to high uptake by plants.