Thesis title: The Impact of Long Term Biosolid Application on Soil Health

Name: Abdul Wahab Mossa

E-mail: armossa@gmail.com

Home institute address: Hejaz Station, Damascus, Syrian Arab Republic, WebSite: http://www.gcsar.gov.sy

Host institute address: University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

Abstract

The disposal of biosolids poses a major environmental and economic problem. Agricultural use is generally regarded as the best means of disposal. Although the impact on soil ecosystems remains uncertain. Biosolids can improve soil properties by supplying nutrients and increasing organic matter content but there is also a potentially negative impact arising from the introduction of heavy metal contaminants into soils. It is widely acknowledged that the bioavailable fraction, rather than total metal content, is indicative of plant metal uptake and toxicity. The bioavailable metal fraction in turn is dependent on soil properties. Therefore, the overall aim of this work was to determine the bio-geochemical factors that control the dynamics of trace element bioavailability in soils that have been subject to the disposal of sewage sludge for over 100 years. Three main investigations were undertaken. In order to determine the current metal composition of the site and identifying the geochemical factors that control the dynamics of metals bioavailability, thirty -eight fields, from a dedicated sewage sludge disposal site for over 100 years, were sampled for both soil (bulk and rhizosphere) and plant. Special attention was devoted to determining soil properties that govern metal partitioning between different metal pools (i.e. total, isotopically exchangeable, $Ca(NO_3)_2$-extractable and free ion activity).

In order to identify the best estimate of plant uptake and toxic response, a pot experiment was carried out to compare the effects of Zn on plant growth in soils recently spiked with Zn and soils historically amended with biosolids to identify soil properties that best predict metal uptake and subsequent phytotoxicity.

The effect of biosolids on soil microorganisms was assessed. Terminal restriction fragment length polymorphism, a fingerprint molecular technique, in combination with multivariate data analysis were used to relate soil microbial diversity and community structure to metal accumulation and bioavailability.

High levels of contamination, exceeding the current limits for the use of biosolids in agriculture, were observed in the studied soils reflecting extensive long-term biosolid application. Enrichment factors in relation to background levels in the area were greater than 5 and followed the trend Cd>Cu>Zn>Pb>Ni. Copper and Cd exhibited extremely high enrichment levels, up to 106 and 151 respectively.

Except for Pb, the isotopically exchangeable pool of the studied metals (*E*-value) was mainly controlled by the total metal content in soil, accounting for more than 90% of the variation in *E*-values. Lead lability was primarily controlled by the total P, LOI and Fe oxides. Metal labilities expressed as % of total metal content were <40% for the five studied elements following decreasing order of Cu > Cd > Zn ≈ Ni > Pb.

Apart from Pb, all the bioavailability estimates (total, E-values, $Ca(NO_3)_2$-extractable and free ion activity) correlated strongly with metal concentration in plant, accounting for more than 70% of the variation in plant concentrations. $Ca(NO_3)_2$-extractable provided the best estimate out of the four measures of bioavailability, accounting for 87, 77, 87 and 83% of the variation in plant concentration of Ni, Cu, Zn and Cd respectively.

The results of the pot trial showed that 67-90% of the added Zn remained isotopically exchangeable after 3 months of Zn addition, suggesting that rapid adsorption processes take place, followed by a slow aging process that cannot be detected over the period of the experiment (3 months). The speciation of soil solution showed that Zn was present mainly (80% on average) as free ion indicating the low affinity of this metal to complexation by dissolved organic matter. An antagonistic relationship was observed between Zn and Cd suggesting that greater Zn availability suppressed Cd uptake by plant. Although Zn addition increased Cd concentration in the soil solution, Cd transfer factor was simultaneously inversely correlated with Zn concentration in soil solution.

The free ion activity model (FIAM), based on the biotic ligand model (BLM), accounted for 94% of the variation Zn concentration in plant. Cadmium appeared to play an important role in competing with Zn for uptake. A simple regression model utilising soil total Zn, soil organic matter and soil pH accounted for 88% of the variation in plant uptake. This indicates the possibility of using soil properties that are measured routinely as input for prediction of plant uptake. The results of the Zn phytotoxicity test indicated that the intensity of the exposure (i.e. free ion activity) was the key quantity in the context of predicting plant toxic response, describing 80% of the variation in the response of barley growth to Zn toxicity. Only labile Zn from the quantity based extraction was able to describe the toxic response explaining only 46% of the variation.

The study of the effect of biosolids on soil microorganisms showed that soil total Zn concentration could be adopted as a good indicator of the overall (historical) biosolids loading. A biosolids loading, equivalent to 700 – 1000 mg kg^{-1} Zn appeared to be optimal for maximum bacterial and fungal diversity. This markedly exceeds the maximum soil Zn concentration of 300 mg kg^{-1}permitted under the current UK Sludge (use in agriculture) Regulations. Redundancy analysis (RDA) suggested that the soil microbial communities had been altered in response to the accumulation of trace metals, especially Zn, Cd, and Cu.

Based on the findings of this thesis, it can be concluded that (i) the estimation of metal speciation, both in the solution and solid phase is a key factor in determining the bioavailability and thus, has greater chemical and biological significance than soil total metal content; (ii) the maximum beneficial effect of biosolids on soil microbial diversity occurred at a metal (Zn) concentration well in excess of current regulations governing application of biosolids to agricultural land. This indicates that soil microbial diversity is unlikely to be determining factor for regulatory limits for biosolids disposal to agricultural lands.