Copper and zinc dynamics and bioavailability in soils amended with biosolids

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy in Soil Science at Massey University, Palmerston North, New Zealand

Paramsothy Jeyakumar

2010

MASSEY UNIVERSITY

Abstract

Global sewage sludge (biosolids) production is increasing as a result of rapidly growing human population and ensuing industrial activities. Land application of this waste is becoming a serious environmental issue because the high levels of heavy metals in biosolids can upset soil microbial activity and nutrient balance when the waste is added to forest or agricultural lands. It is widely accepted that bioavailability, rather than total soil concentration, is more important when assessing the risk associated with metal contamination. The bioavailability of a heavy metal is dependent on the chemical nature of the metal, the chemical, physical and biological properties of biosolids that contain the metal and of soil that receives the biosolids. It also depends on the interaction of the biosolids with soil, plants and soil microorganisms. The overall aim of this thesis was to assess the bioavailability of biosolids–derived Cu and Zn and the comparative effects of these metals on plant and soil microbial activity, with special attention to mycorrhiza, and the effects of application of lime and Al dross as ameliorants for the reduction of bioavailability of these two metals.

Biosolids were collected from the Palmerston North City Council Waste Water Treatment Plant (PNCCWTP) sludge lagoon in Palmerston North, New Zealand. Because the metal concentrations were low, for research purposes these biosolids were spiked separately with three levels of Cu (to give final concentrations of 50, 150 and 250 mg/kg soil) and Zn (to give final concentrations of 150, 450 and 750 mg/kg soil) added as metal sulphate salts. The biosolids were anaerobically incubated, and it was found that a shorter period of equilibration (2 months) than the previously used 6–9 months was sufficient for Cu and Zn to be fully incorporated into the biosolids matrix. As biosolids in New Zealand are currently applied to forest lands, two important forest plants, poplar and pine, were considered for the study in this thesis. The effects of elevated concentrations of Cu and Zn in a soil amended with metal spiked biosolids on poplar plants were investigated in a 147 day glasshouse pot trial. The findings of this trial showed that at the same total soil metal concentration, biosolids–derived Cu was more

toxic than Zn to soil microorganisms, whereas Zn was more toxic to poplar and ECM fungi. In a similar glasshouse study lasting 312 days with pine, Cu did not show a phytotoxic effect, but Zn was phytotoxic to pine. However, both metals were toxic to microorganisms and neither metal influenced ECM fungi colony development. The currently recommended maximum metal concentration limits for New Zealand soils of 100 mg/kg for Cu and 300 mg/kg for Zn appear to be high for both metals with respect to soil microbial activity, but low for Cu and high for Zn with respect to poplar and pine growth.

A laboratory incubation trial with Cu– and Zn– spiked biosolids added to eight soils representing the major Soil Groups collected from across the North Island of New Zealand (biosolids added to give final soil concentrations of 150 mg/kg for Zn or 450 mg/kg for Cu), showed that crystalline Fe oxide was the dominant factor explaining 90% of the variability in exchangeable Cu. For Zn, clay content and pH were the controlling soil factors that together explained 73% of the variability in exchangeable Zn. An increased content of crystalline Fe oxide increased the soil exchangeable Cu concentration. Decreasing pH and increasing clay content increased the soil exchangeable Zn concentration.

The effect of lime (0.1 and 0.5%), Al dross (2 and 6%) and a combination of lime and Al dross (0.1% lime+2% Al dross) as soil amendments for the amelioration of the toxic effect of biosolids–derived Cu (144 mg/kg in soil) and Zn (417 mg/kg in soil) on microorganisms and poplar were also studied. Results revealed that application of lime and Al dross (pH 10) as a mixture (0.1% lime+2% Al dross) was able to ameliorate Cu and Zn phytotoxicity, and significantly increase the DM yield of poplar, ECM fungi population and microbial activity in the Cu and Zn contaminated soils.

The findings of the studies in this thesis are applicable to environmental regulations with respect to heavy metal limits that seek to protect agricultural and forest land, human and animal health, and soil and drinking water quality, in scenarios where biosolids are applied to soil.

Acknowledgements

Mere words cannot be conveyed to express my worship to my God, for providing me with the strength, knowledge, wisdom, courage and love. I would like to acknowledge this land of the long white cloud, the traditional land of the Mãori and Pakeha people for giving me this valuable opportunity.

It is indisputably my proud privilege to express my deepest sense of gratitude to Associate Professor P. Loganathan, my chief supervisor for his tremendous support during my times of hardship, his enthusiasm, deep scientific insights and expert discussions, wisdom and guidance, motivation and inspiration, service mind, and for having faith in me.

I am sincerely grateful to my co–supervisor Dr. Christopher W. N. Anderson, an insightful friend, a pillar of practical work and laboratory support and source of wisdom and enthusiasm. I would like to thank my co–supervisor Professor Ron G. McLaren for his valuable scientific inputs and advices throughout the entire period of my doctoral study.

It is my pleasure to express my heartfelt gratitude to Dr S. Sivakumaran for his excellent support in microbiology experiments, patience and critical eye, and continuous support.

I am grateful to New Zealand Soil Science Society for selecting me for prestigious best PhD student award (Summit–Quinphos) in 2009. Many thanks also to World Bank aided IRQUE project, Eastern University of Sri Lanka, Massey University Doctoral Scholarship for providing me the financial assistance during the three years of my research. I wish to thank Education New Zealand for providing New Zealand Postgraduate Study Abroad Award for attending overseas international conference. I also wish to thank Institute of Natural Resources for funding this study, Helen E Akers PhD scholarship as well as providing travel grant to attend national and overseas conferences.

I am indeed thankful to staff of the Soil and Earth Sciences Group especially to Professor Mike Hedley, Mr Lance Currie, Ms Ann West, Mr Ian Furkert, Mr Bob Toes, Mr Ross Wallace, Ms Glenys Wallace, Mr Mike Bretherton, Ms Moira Hubbard and Ms Liza Haarhoff for their priceless support, and encouragement at each step of research period have been the driving force of this work. I would especially like to thank Dr Brent Clothier and staff of climate lab, Plant and Food for hosting me for my microbial experimental work. Many thanks for Palmerston North City Council Waste Water Treatment Plant and staff member for giving permission to collect biosolids and for their worthwhile information. My sincere thanks to RST Environmental Solutions Ltd, Palmerston North, New Zealand for providing poplar cuttings, and Stéphanie Caille for measuring ECM mycorrhizae colonized roots infection.

I owe a big thanks to my dear friend Erwin Wisnubroto for always being kind, extremely helpful and supportive during my difficult stages of PhD. My sincere thanks to Peter Bishop, Janice Asing, Raza Khan and Saleem Bhatti and other research fellows in the Soil and Earth Group for their invaluable assistance in research work.

I am indeed thankful to Jeevi Ponniah, Jayanthy Ramaneeswaran, Luxmy Thiyagalingam, Sylvia Fransis and Valarmathi Jeyamohan for their extreme support to keep me balance between academic and family life.

Words are not enough to express my love and thanks to my father, sister, brother–in–law, brothers, sister–in–laws and kids for all their love, understanding, help and encouragement. My heartfelt respect to my dearest mother who always up and, loved me, was so proud of me, believed in me, supported me and was there for me.

My son – Ganan and little princess – Vibu, your love, your life and your future was my inspiration and motivation!!! Finally, rest of all my energy goes to a wonderful woman – Vaithehi. A person, who believes in me, always supports me, who loves me, cares for me, no matter what. A true inspiration to my life!!!

Table of contents

List of figures

List of tables