ARSENIC IRRIGATED VEGETABLES: RISK ASSESSMENT FOR SOUTH ASIAN HORTICULTURE

A Thesis presented in fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Soil Science

Massey University Palmerston North New Zealand

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2013

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ABSTRACT

Arsenic (As) contaminated water is often used in South Asia to irrigate vegetables. These vegetables accumulate As in their edible tissues and once ingested, increase As burden in humans. Despite the apparent risk, the As uptake potential of vegetable species when irrigated with As-contaminated water is not well defined. Most research on As-irrigated vegetables are monitoring surveys that only describe the As concentration levels in various vegetable species from affected areas. Because of the great variability in As concentration of irrigation water, soil type, vegetable species and cultivars, agronomic practices and climatic factors, As uptake potential of an individual vegetable species cannot be described from the monitoring data. Identifying vegetable species and soil conditions that result in high As concentrations in the edible tissues of vegetables is prerequisite for risk assessment and proposing As mitigation strategies.

The objectives of this study were to (i) determine the As uptake response of common vegetable species when irrigated with As-contaminated water, (ii) calculate the risk to humans upon ingestion of As-contaminated vegetable species, (iii) elucidate factors that may increase As concentrations in vegetable species, and (iv) propose management strategies for South Asian countries where As-contaminated water is used for vegetable cultivation.

In the first glasshouse experiment (Chapter 4), four common vegetables, carrot (*Daucus carota*), radish (*Raphanus sativus*), spinach (*Spinacia oleracea*), and tomato (*Solanum esculentum*) were irrigated with a range of As^{V} enriched water (50 to 1000 µg L^{-1}) using two irrigation techniques. These irrigation techniques were (i) non-flooded, where soil moisture was maintained to 70% field capacity (Fc) of soil, and (ii) flooded, where the water was maintained at 110% Fc initially followed by drainage and onset of aerobic conditions until the next irrigation event. Only the 1000 µg As L^{-1} treatment showed a significant increase of As concentration in the vegetables compared to all other treatments. There was a higher concentration of As in the vegetables grown under flood irrigation relative to non-flood irrigation. The trend of As uptake among vegetable species was spinach > tomato > radish > carrot. Only in spinach leaves, the As concentration was above the Chinese food safety standard for inorganic As (0.05 µg g^{-1} fresh weight) by a factor of 1.6 to 6.4 times, when irrigated with 100, 200, and 1000 µg As L^{-1} under flood irrigation and with 1000 µg As L^{-1}

under non-flood irrigation. The USEPA carcinogenic and non-carcinogenic risk parameters for the scenario where vegetables are consumed 500 grams per day were calculated. The USEPA Hazard Quotient (HQ) value for spinach leaves ranged from 0.32 to 1.26 for adults and 0.38 to 1.51 for adolescents while the Cancer Risk (CR) value ranged from 1.4×10^{-4} to 5.7×10^{-4} for adults and 1.7×10^{-4} to 6.8×10^{-4} for adolescents for treatment water concentrations 100 µg As L^{-1} or greater. An HQ value greater than 1 represents an unacceptable non-carcinogenic risk and a CR value greater than 10^{-4} represents an unacceptable carcinogenic risk.

A laboratory batch experiment (Chapter 5) was conducted using four soils to determine their As adsorption behavior and the soil properties that control As retention in these soils. Soils used in this study were (i) Rangitikei silt loam (the soil which was used in glasshouse experiment 1), (ii) Rangitikei silt loam soil amended with calcium hydroxide to raise the pH to 7.5, to model the soil pH level of South Asian countries, and (iii) two New Zealand soils, Korokoro silt loam and Tokomaru silt loam. Both arsenate (As^{V}) and arsenite (As^{III}) were investigated in the experiment because these As species are mainly present in irrigation water. The results showed that the As^{V} was adsorbed to a greater degree than As^{III} as defined by high adsorption maxima, bonding energy and As partition coefficient values of Langmuir and Freundlich isotherms. Adsorption of both As^{V} and As^{III} was mainly controlled by amorphous Al, total C and Olsen P content of selected soils.

A glasshouse experiment (Chapter 6) was conducted to explore those factors which can promote As concentration in plants. The following factors which are likely to affect horticulture in South Asia were included: two As species (As^{V} and As^{III}), four As concentration levels of irrigation water (50 to 1000 µg L^{-1}), two soil pH levels (6.1 and 7.5), and two soil amendments (biochar and cattle manure). The control treatment for this experiment was no As in irrigation water and no soil amendment. Spinach was selected for this work due to its high uptake potential described in the earlier glasshouse experiment (Chapter 4). The findings of this experiment showed that the As concentration in spinach leaves was dependent on As concentrations in water and soil amendments and was independent of soil pH and As species under flood irrigation. Spinach plants grown in biochar and cattle manure amended soils had significantly higher As concentration in their leaves when compared with spinach plants grown with no amendment. In both biochar and cattle manure amended soils, the As concentration in spinach leaves exceeded the Chinese food safety standard (0.05 μg g^{-1} fresh weight) by a factor of 1.6 to 8.3 times, where the concentration of As in irrigation water was 200 μg L^{-1} or greater. The CR values for spinach grown in cattle manure amended soil was greater than the critical value of 1 x 10^{-4} for the scenarios where vegetable consumption is 205 grams and/or 500 grams per day. This increase was found where the As concentration in irrigation water was 200 μg L^{-1} or greater. The HQ value was above the critical value of 1 for the scenario where the vegetable consumption is 500 grams per day. This increase was observed for spinach grown in cattle manure amended soil with an As concentration in irrigation water 500 μg L^{-1} or greater. Arsenic daily intake (mg kg^{-1} body weight) associated with the ingestion of spinach leaves corresponds to proposed ATSDR (Agency for Toxic Substances and Disease Registry) and drinking water daily intake values that may lead to development of cancer (bladder, lung and skin), skin lesions, and intellectual impairment in children. The As intake through ingestion of spinach correlates to an As concentration in drinking water that is 10 μg L^{-1} or greater.

Overall, the results of glasshouse studies indicate that the As concentrations greater than 50 μg L^{-1} should be avoided for spinach cultivation where flood irrigation is practiced. Addition of cattle manure can further intensify the risk by increasing the As concentration in plant tissues, therefore its usage in South Asian horticulture is questionable. I propose that the As concentration in vegetables should not be overlooked as they can alone be a major source of As poisoning in humans.

DEDICATION

This work is dedicated to my parents for their hard work

ACKNOWLEDGEMENTS

I give thanks to the Lord, Jesus Christ, for He gave me strength and wisdom to finish this task. He helped me and my heart is filled with joy.

I deeply acknowledge my chief supervisor, Dr. C. W. N. Anderson for his guidance and help during the entire period of study. He is a brilliant man, with exceptional qualities, friendly attitude and encouraging spirit. I am grateful to my co-supervisors, Dr. R. B. Stewart and Dr. B. H. Robinson for their advice and scientific inputs for research and refining this manuscript.

I greatly acknowledge the Higher Education Commission of Pakistan (HEC) for the award of PhD scholarship at Massey University New Zealand. Sindh Agriculture University Tando Jam, Pakistan is acknowledged for granting me study leave to purse PhD degree. I give thanks to Soil and Earth Sciences group, Massey University New Zealand, and New Zealand Soil Science Society for financial assistance to attend the 5th Joint Australian and New Zealand Soil Science Conference, 2-7 December 2012, Hobart, Tasmania, Australia. The Claude McCarthy Fellowship and Dr. C. W. N. Anderson are acknowledged for their financial support to attend the 12^{th} International Conference on the Biogeochemistry of Trace Elements (ICOBTE), June 16-20, 2013, Athens Georgia, USA. Dr. C. W. Anderson is further acknowledged for provision of one month scholarship.

I admire the support of Hoult Contractors Ltd. Palmerston North, who provided the soil used in the study. The New Zealand Biochar Research Centre (NZBRC) is acknowledged for providing biochar for this research. I am thankful to Peter Bishop and Roberto Calvelo Pereira for biochar analytical work.

Many thanks to the staff of Soil and Earth Sciences group for their support especially Professor Mike Hedley, Marta Camps, Alan Palmer, Liza Haarhoff, Lance Currie, Bob Toes, Ian Furkert, Ross Wallace, Mike Bretherton, Glenys Wallace, and Anja Moebis. Dr. Xiong Zhao He is acknowledged for his help in statistical analysis.

I appreciate the help, support and friendship of Amandeep Singh, Neha Jha, Jeyakumar, Razaullah Khan, Kiran Hina and Tao Wang.

I deeply remember my late father for his vision of higher education for me. Had he been alive he would have been proud of me for this achievement. I acknowledge my mother for her love, support and prayers for me. My brother and sisters' support and prayers will always be remembered.

I express my gratitude to my wife, Fouzia George, for her support, care and love for each day. My son, Shalom Bhatti, has been a blessing and inspiration for me. His smile and affection was comfort and a reason to move forward.

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