BORON DYNAMICS AND AVAILABILITY IN *PINUS RADIATA* PLANTATION

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

Doctor of Philosophy

in

Soil Science

Institute of Natural Resources, College of Sciences Massey University, Palmerston North,
New Zealand

Raza Ullah Khan

2012

Abstract

Pinus radiata is an important forest species in New Zealand. Over 89 % of the country's plantation forestry area is planted with *P. radiata.* The species makes a major contribution to New Zealand's $3.1 billion to GDP and the plantation area is projected to increase to 2.5 million hectares by 2025. Research work to date has recognised that soil B deficiency is a major issue in many forestry plantation areas. Edaphic and environmental conditions such as the coarse texture pumacious soils planted with radiata in the Central North Island, and summer drought condition in some areas, further aggravate B deficiency in New Zealand soils.

Boron deficiencies in *P. radiata* lead to growth defects in afflicted plants and a deterioration in wood quality and market value. The primary objective of this thesis was to assess the impact of ulexite, a slow-release B fertiliser, on the bioavailability of soil B, plant B uptake, and the relative effect of B application rate on plant growth and soil microbial activity. A further objective was to compare the rate of B adsorption to seven benchmark soils collected from the North Island of New Zealand. The purpose of the work was to propose a long-term slow-release fertiliser management solution for radiata pine forestry that may mitigate the economic damage caused by B deficiency in this important primary production sector.

Soil was collected from Taupo, the major *P. radiata* planting district in the Central North Island of New Zealand, and used to establish glasshouse studies with *P. radiata* at Massey University in Palmerston North. Plants for this research were obtained from the Forest Research Institute (SCION) in Rotorua, New Zealand. Two growth experiments were conducted. The second of these compared the B dynamics of a fast-growing and slow-growing clone of *P. radiata*.

The background concentration of B in this soil (less than 0.5 mg/kg calcium chloride extractable B) is low, and B fertiliser application induced a soil response. Results showed that the concentration of plant-available B (extracted using hot 0.02 M $CaCl_2$) significantly increased with B application. Boron application at the highest level (32 kg/ha) led to a build-up of soil B to a critical toxicity level with the subsequent appearance of toxicity symptoms in plants.

Application of B resulted in rapid B uptake as shown by an increase in B concentration in all plant parts (needle, stem and roots), but with the greatest rate of increase in needles. The percentage distribution of B throughout the plant showed that B distribution was influenced by B application treatments. The root to needle B ratio is used in this work as an index of B transfer from source to sink parts of a plant. Results showed that under deficient and toxic soil B concentrations (defined through the $CaCl_2$ extractable B concentration), B was restricted to source tissues. However, B application at the rate of 4 kg/ha enabled B to move to sink parts including the new emerging needles. Regardless of clone and B treatment, needles, particularly older needles, were the main site of B accumulation followed by roots and stem. The B concentration in needles of Clone 37 was higher than in Clone 18 and this result reflects a higher demand of B for the faster growing Clone 37 relative to Clone 18.

Application of B affected *P. radiata* growth in terms of height, diameter and plant dry weight. Plants responded positively to B application over a range of fertiliser treatments (8-16 kg/ha) leading to sufficiency in soil as quantified through increases in the plant growth parameters plant height and dry weight. Boron application improved plant physiology as quantified by photosynthesis in this study. Results showed that photosynthesis positively responded to B application up to 8 kg/ha, however a further increase in B application resulted in a decline in photosynthetic activity.

Results from a B fractionation study showed that the plant unavailable residual-B fraction was the major form of B in the Taupo soil. With B fertiliser application the concentration of readily-available B increased proportionally to the B application rate. This increase in readily-available B demonstrates the importance of using B fertiliser to provide for a long-term increase in plant-available soil B for *P. radiata* plantations on the Taupo soil.

Soil microbial and microbiological properties also responded to B application. Soil dehydrogenase activity, an index of microbiological activity in soil, showed a concentration gradient from the bulk to rhizosphere soil. Regardless of clone there was approximately a three-fold higher dehydrogenase activity in the rhizosphere soil compared to the bulk soil. Maximum dehydrogenase activity was recorded by a B application at 4-8 kg/ha in both clones with a decrease in activity at higher rates.

Regardless of the radiata clone used, mycorrhizal colonisation increased with B application. However, for both clones the maximum mycorrhizal infection on roots was recorded for a B application rate of 2-4 kg/ha.

A B adsorption study performed using seven benchmark soils collected from around the North Island showed that B adsorption increased in all soils with the concentration of B in equilibrium solution. Langmuir and Freundlich isotherms modelled B adsorption in all seven soils. Further studies showed that B adsorption corresponded to pH in solution and linearly increased up to pH 9 and reduced thereafter.

The results from this study demonstrate the importance of B fertiliser to *P. radiata* plantation forestry. Both plant and microbiological parameters are affected by both low and excess levels of soil B. Therefore, it is suggested that a B application rate in the range of 4-8 kg/ha is optimal for plant growth and will have no harmful effect on soil microbiological parameters. In contrast, B application at the rate of 16 kg/ha is toxic to both plants and soil microbes and will lead to inhibitory effects on activity and growth.

Acknowledgements

First of all I am enormously thankful to Allah the Most Merciful and the Most Beneficient who grants me strength, courage, wisdom and knowledge to accomplish this task. I feel deep pleasure to appreciate the following people and institutions for their valuable contribution towards completing this thesis and make my student life a wonderful experience at Massey University.

I would like to express my sincere gratitude to my chief supervisors, Dr. Christopher W.N. Anderson and Associate Professor Dr. P. Loganathan for their ceasless supports, enthusiasm and hardworking spirits that gifted me scientific insight and strengthened my personality. I am also thankful to my co-supervisors, Jianming Xue and Peter Clinton (SCION) for their guidance, continuous contact and help in drafting this thesis. All these personality helped me a lot.

I am also indeed thankful to all staff of Soil and Earth Science Group especially Professor MJ Hedley (Head-Soil and Earth Science Group), Dr. Alan Palmer, Dr. Bob Stewart, Dr. James Hanely, Mr. Lance Currie, laboratory technician; Ian Furkert, Bob Toes, Ross Wallace, Gleny Wallaces, Ann West, Mike Bretherton and group secretaries; Denise, Moira and Liza Haarhoff for helping in labortaries analytical procedure, graphics and statistical analysis.

I am also thankful to Dr. S. Sivakumaran and other support staff of Plant and Food Palmerston for allowing me using their labartory for mycorrhizae isolation work.

My sincere thanks go to Ms. Sylvia Hooker, Ms. Diane Reily and Dr. Zulfiqar Butt (International student support office, Massey University) for their enormous support, useful suggestion and hospitality.

I am also grateful to Higher Education Commission (HEC), Govt. of Pakistan for granting me scholarship to pursue my PhD studies in Massey university. My sincere thanks are also due to Pakistan Agricultural Research council (PARC) for the admittance to pursue my PhD studies at Massey university.

I wish to address my special thanks to I am also grateful to the staff of Forest Institute Rotorua and Christchurch for their help in providing financial and logistic

help and staff of Plant Growth unit; Steven, Lindsay, Lesley and Scott for setting up glasshouse trial.

I wish to express my thanks to Dr. Mohammad Shuaib, Dr. Wajid Hussain, Dr. Mohammad Zaman and their families for help and hospitality throughout my stay in New Zealand. I am also grateful to my friends; Jeyakumar, Indica, Toe, Saman, Roberto, Abdul Hanan, Shakeel, Sajjad, Sadaf, Kiran, Asad, Shujjat, Murad, Atif and Zia.

Finally, I am thankful to my beloved wife Rehana Gul, my lovely daughters; Manahil and Mashaal, my beloved son Ahsan Raza who shared their love during my studies. I am grateful to my parents, my brothers; Dr. Engineer Atta Ullah Shah, Zia Ullah Shah, Professor Dr. Salim Ullah Khan, Dr. Irfan Ullah Jan and rest of my family members whose love, understandings and consistent encouragements; have greatly helped me in completion of this thesis.

Raza Ullah Khan

Palmerston North, 2012

Dedication

I dedícate this thesis to my late Great Grandmother

TABLE OF CONTENTS

List of Figures, Tables and Equations