Root-soil-phosphate interactions in rice growing in aerobic soil

A thesis presented in partial fulfilment of the
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TO WHOM IT MAY CONCERN

This is to state the research carried out for my PhD thesis entitled "Root-soil-phosphate interactions in rice growing in aerobic soil" in the Institute of Natural Resources, Massey University, Turitea Campus, New Zealand and in the Soil and Water Sciences Division of the International Rice Research Institute, Los Baños, Philippines, is all my own work.

This is also to certify that the thesis material has not been used for any other degree.

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Supervisor: M.J. Hedley
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Date: 31/10/00

Abstract

Rice (*Oryza sativa* L.) is the staple food of subsistence farmers in the vast areas of Ultisols and Oxisols of the tropical and subtropical rainfed uplands and lowlands. Phosphorus (P) deficiency and soil acidity commonly constrain yields. Phosphorus fertiliser is considered an expensive input, and must therefore be used efficiently. The objective of this thesis was to investigate fertiliser strategies and plant mechanisms that could enhance the uptake efficiency of P by aerobically grown rice. The long-term aim of understanding rice P-uptake mechanisms is that such research will help in developing P-efficient rice varieties.

In acid soils, aluminium (Al) toxicity restricts root growth and therefore limits P uptake. A bioassay was developed as a basis to compare two techniques for assessing concentrations of phytotoxic Al. It was found that Al in soil solution extracted by centrifugation correlated better with rice root extension than Al extracted in 0.02 M $CaCl_2$. Aluminium toxicity was found not to restrict root growth (hence P uptake) in the Philippines Ultisol (Cavinti soil) used in later experiments.

Experiments investigating the effect of different fertiliser management practices, showed that banding of fertiliser P, as opposed to incorporating P fertiliser throughout the soil, enhanced the availability of P to rice grown in the high P-fixing Cavinti soil. The practice of applying green manure with reactive phosphate rock (RPR) decreased the dissolution of RPR because mineralisation of green manure nitrogen increased the soil pH.

Aerobically grown rice exhibited a number of mechanisms that would enhance P uptake: rhizosphere acidification, localised proliferation of fine roots in P-rich zones, and association with mycorrhizae. Mathematical modelling indicated that upland rice must be able to release solubilising agents, e.g. organic anions, in order to explain the observed P uptake in banded, moderately fertilised soil. By extracting soil fertilised at different P rates with citrate solutions, it was found that more P was extracted, per mole of citrate added, from highly fertilised soil. This indicated that there would be a positive interaction between banding fertiliser P and solubilisation by organic anions. Initial extraction, storage and detection methods were unable to identify significant quantities of organic acids in the rhizosphere of aerobically grown rice. Better methods for extracting organic anions from soil were developed, and improved procedures for studying the mechanisms of plant induced changes in the rhizosphere are proposed.

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Symbol	Definition	Units
General symbols		
ρ	soil bulk density	kg dm^{-3}
E_h	equilibrium redox potential	V
g	the unit for relative centrifugal force (RCF) (in this thesis the maximum radius is used to calculate the RCF)	m s^{-2}
Pi	inorganic phosphorus	–
pK	dissociation constant	–
Po	organic phosphorus	–
Symbols used in Model 1		
α	root absorbing power for P (The maximum value of $\alpha = F_{max}/K_m$)	dm s^{-1}
θ	volumetric soil water content	–
A	area of root-soil contact	dm^2
b_P	soil buffer power for phosphorus, d[P]/d[P_L]	–
D_{LP}	diffusion coefficient of P in free solution	dm^2 s^{-1}
f	diffusion impedance factor	–
F_{max}	maximum influx that the roots can achieve	mol dm^{-2} s^{-1}
K_m	Michaelis-Menten constant (K_m = P concentration in solution when P uptake by roots is half of the maximum P uptake)	mol dm^{-3}
L	width of thin layer	dm
l_h	width of the root hair zone	dm
[P]	concentration of phosphorus (P) in the whole soil	µmol dm^{-3} soil
[P_L]	concentration of P in the soil solution	µmol dm^{-3} solution
$[P_L]_0$	the concentration of P in the soil solution at $x = l_h$,	µmol dm^{-3} solution
t	time	s
x	distance	dm

Symbol	Definition	Units
Additional symbols used in Model 2 (solubilisation by citrate (C))		
b_C	soil C buffer power, $(\partial[C]/\partial[C_L])_P$	–
b_{P*}	soil P^* buffer power, $(\partial[P]/\partial[P_L^*])_C$	–
[C]	concentration of C in the whole soil	μmol dm^{-3} soil
$[C_L]$	concentration of C in the soil solution	μmol dm^{-3} solution
D_{LC}	diffusion coefficient of C in free solution	$dm^2\ s^{-1}$
D_{LP*}	diffusion coefficient of P* in free solution	$dm^2\ s^{-1}$
F_C	flux of C across root plane	mol $dm^{-2}\ s^{-1}$
k_C	rate constant for C decomposition	s^{-1}
$[P_L^*]$	concentration of P species (ortho P and P complexed with C) in the soil solution	μmol dm^{-3} solution
λ_C	P-C interaction coefficient, $(\partial[P_L^*]/\partial[C_L])_P$	–
Additional symbols used in Model 3 (solubilisation by the hydrogen ion (H^+))		
b_H	H^+ ion buffer power, $(\partial[H^+]/\partial[H_L^+])_P$	–
D_{LH}	diffusion coefficient of H_3O^+ in free solution	$dm^2\ s^{-1}$
F_H	rate of H^+ release	mol $dm^{-2}\ s^{-1}$
[H]	concentration of soil acidity titratable to the original soil pH	mol dm^{-3} soil
$[H_L]$	concentration of H_3O^+ in the soil solution	mol dm^{-3} solution
k_H	H^+ decomposition rate constant	s^{-1}
p_{CO2}	partial pressure of CO_2	atm
pH_i	initial pH	–
λ_H	P-H^+ interaction coefficient, $(\partial[P_L^*]/\partial[H_L])_P$	–