

Plant Nutrition for Food Security, Human Health and Environmental Protection

C. J. Li
F. S. Zhang
A. Dobermann
P. Hinsinger
H. Lambers
X. L. Li
P. Marschner
L. Maene
S. McGrath
O. Oenema
S. B. Peng
Z. Rengel
Q. R. Shen
R. Welch
N. von Wirén
X. L. Yan
Y. G. Zhu
editors



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Preface

The world's population is expanding rapidly. The status of daily food consumption is also changing, from survival-based eating to luxury and excessive eating for many people, especially in the more developed areas and countries of the world. Production of enough food to meet the need of the increased population, and of more livestock, fish and horticulture and industrial raw material crops to satisfy the increased living standard of people, are really a big challenge for modern agriculture.

Improving human health is a key component of the future agriculture globally. Therefore, food production is not only a quantitative challenge. It is known that micronutrient deficiencies are a massive global problem affecting over 3 billion people worldwide, mostly women, infants and children in resource-poor families in the Global South (Mason and Garcia 1993). Plant Nutrition requires the application of knowledge from basic to applied research, to improve the nutrient status of crops which is helpful for the health not only for plants themselves, but also for that of humans.

Besides breeding plant genotypes with increased efficiency to use soil and fertilizer nutrients, increasing fertilizer input on the limited land available for crops is a common way to increase crop yield, to feed the rapidly increasing world population. However, continued excessive use of fertilizers in many countries has led to the build-up of soil nutrient stocks which resulted in increased nutrient fluxes and off-site effects. Efficient use of fertilizers, optimizing crop yield and minimizing environmental pollution is therefore a critical issue.

The theme of this Colloquium is Plant Nutrition for food security, human health and environmental protection. The contributions compiled in this book provide an excellent overview of current research in these areas.

The Proceedings are published *before* the opening of the Colloquium, so that all participants can have it in hand during the Colloquium. Up to date, more than 800 scientists from 51 nations and regions have registered. Nine plenary and a further 28 keynote speakers and 131 oral presentations have been invited. It has been a tremendous effort to compile about 600 contributed papers as Proceedings on time. We wish to express our deep gratitude to the conveners for their recommendation of plenary speakers, selection and proposal of keynote speakers, and decision of oral and poster presentations for each symposium. Especially, we would like to express our sincere thanks to N. von Wirén (S1), Z. Rengel (S2), Q. R. Shen (S2), R. Welch (S3), P. Hinsinger (S4), X. L. Yan (S4), H. Lambers (S5), S. McGrath (S6), Y. G. Zhu (S6), P. Marschner (S7), X. L. Li (S7), S. B. Peng (S8), L. Maene (S8), A. Dobermann (S9), and O. Oenema (S9) for their review and editing of the contributions. Because of the tremendous amount of work and limited time for publication, it is impossible to avoid some mistakes in this book. We therefore apologize in advance to authors and readers for any possible imperfections in the publication of the Proceedings.

Finally we would like to express our sincere thanks to the International Council on Plant Nutrition for selecting China to host the 15th International Plant Nutrition Colloquium. This year, there can surely be no better location than Beijing and China. Not only is this an historic location and agricultural country, but, more importantly, Plant Nutrition has developed very rapidly in the last decade and played a very important role in food security, human health and environmental protection. We would also like to express our thanks to the local organizing committee from CAU for their hard and pleasant teamwork in preparing the Colloquium. We trust that all participants will be satisfied with the program and enjoy the Colloquium and Beijing.

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C. J. Li
F. S. Zhang

A study about nutrient uptake by roots. a moving boundary model. Determination of kinetic parameters

J.C. Reginato¹⁾ and D.A. Tarzia²⁾

¹⁾ The Physics Department, Sciences Faculty, National University of Rio Cuarto, Rio Cuarto - Cordoba, Argentina.
X5804BYA jreginato@exa.unrc.edu.ar

²⁾ The Mathematics Department, Management Sciences Faculty, Austral University, Rosario, Santa Fe, Argentina.
S2000FZF

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Abstract

The Barber-Cushman model is widely used to estimate the single nutrient uptake by a growing root system. The model solves the coupled equations of transport in the soil and absorption of nutrient by roots in fixed domains. The objective of this study is to determine whether a dynamical model, accounting for increasing root competition, could improve predictions of nutrient uptake. Our model includes assumptions of the Barber-Cushman model and the moving boundary approximation. The model predicts nutrient uptake by coupling nutrient flux to roots and nutrient absorption on a variable domain in time. The integral balance method and the immobilization domain method with two finite differences schemes were applied. The three model outputs were compared with measured and predicted (Barber-Cushman model) uptake of Mg, K, and P by pine seedlings.

Introduction

The moving boundary approximation. Nutrient uptake has been evaluated through diffusion and mass flux models based on numerical approximations in fixed domain through transport differential equations coupled with root absorption kinetics (Cushman, 1979). Recently, moving boundary models for nutrient uptake have been formulated (Reginato *et al.* 2000). It is considered to be a one-dimensional model, that is, a single cylindrical root in the soil for which the conditions of humidity, light and temperature are assumed to be controlled (as in a growth chamber) and the governing equations are given by the following expressions:

$$D \frac{\partial^2 C}{\partial r^2} + D(1 + \varepsilon_0) \frac{1}{r} \frac{\partial C}{\partial r} = \frac{\partial C}{\partial t}, \quad s_0 < r < R(t), \quad 0 < t < T$$

$$C(r, 0) = \varphi(r), \quad s_0 \leq r \leq R_0$$

$$-Db \frac{\partial}{\partial r} C(R(t), t) + v_0 C(R(t), t) = 0, \quad 0 < t < T$$

$$Db \frac{\partial}{\partial r} C(s_0, t) + v_0 C(s_0, t) = \frac{k_a [C(s_0, t) - C_u]}{1 + \frac{k_a [C(s_0, t) - C_u]}{J_m}}, \quad 0 < t < T$$

$$R(t) = R_0 \sqrt{\frac{l_0}{l(t)}}, \quad 0 < t < T$$

where r is the radial distance from the root axis [m], t is the time [s]; T is the maximum time for which the system has solution [s]; C_u is the concentration for which the net influx is null [mol m⁻³]; v_0 is the mean effective velocity of soil solution at root surface [m s⁻¹]; b is the buffer power, D is the effective diffusion coefficient [m² s⁻¹], k_a ($= J_m / K_m$) is the absorption power of nutrient [m s⁻¹]; J_m is the maximum influx at infinite concentrations [mol m⁻² s⁻¹]; K_m is the concentration at which influx is $J_m / 2$ [mol m⁻³]; $R(t)$ is the variable half distance between root axes

at time t [m], φ is the initial concentration defined in [$s_0, R(t)$] [mol m⁻³], R_0 is the initial half distance between root axes [m], s_0 is the root radius [m], $l(t)$ is the root length as a function of time [m], and l_0 is the initial root length [m].

Results

The model is solved applying the integral balance method and finite differences method (explicit and implicit form) (Reginato *et al.* 2005): the results are shown with data from literature (Kelly *et al.* 1992) (Table 1).

Table 1. Comparison of predictions by the moving boundary model with respect to the Barber-Cushman Model

Observed Uptake (mmol/pot)		Barber-Cushman Model	Integral Balance Method	Explicit Finite Differences	Implicit Finite Differences
Mg	1.617	0.625	0.680	0.18	0.763
K	6.663	6.285	6.653	7.33	7.272
P	1.332	1.185	1.302	1.41	1.409

Radiocaesium uptake. The model is applied to radionuclide uptake (Darrah and Staunton, 2000) and the governing equations are:

$$\frac{\partial C_d}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{Df_L \theta_L}{(b + \theta_L)} \frac{\partial C_d}{\partial r} \right) - \frac{\partial C_r}{\partial r}, \quad r_0 < r < R(t), \quad 0 < t < T$$

$$C_d(r, 0) = \varphi(r), \quad r_0 < r < R_0$$

$$\frac{\partial C_d}{\partial r}(R(t), t) = 0, \quad t > 0$$

$$\frac{Df_L \theta_L}{(b + \theta_L)} \frac{\partial C_d(r_0, t)}{\partial r} = \frac{J_m C_d(r_0, t)}{C_d(r_0, t) + bK_M}, \quad t > 0$$

$$R(t) = R_0 \sqrt{\frac{l_0}{l(t)}}, \quad t > 0$$

coupled with a radionuclide desorption-desorption ordinary differential equation

$$\frac{dC_r}{dt} = \frac{k_r \theta_L}{(b + \theta_L)} C_d - \frac{k_r}{b_2}, \quad C_r(r, 0) = 0$$

The model is solved applying implicit finite differences. The fraction removed from soil by roots was computed by:

$$Fr = \frac{\text{Ions removed by the root}}{\text{Initial ions in soil}}$$

In Figure 1 we show the ^{137}Ce fraction removed from soil by roots vs. time as a function of initial length l_0 . The input data were extracted from Darrah and Staunton (2000).

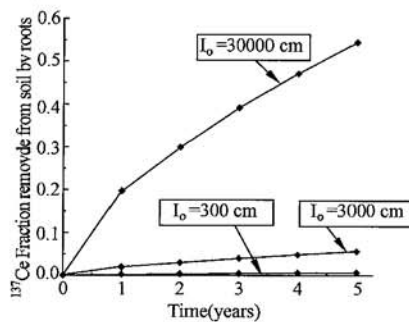


Figure 1. ^{137}Ce fraction removed from soil by roots vs. time as a function of initial length l_0 .

Calculations made to consider the effect of root growth velocity k_1 have shown that the differences between Darrah-Staunton and our predictions are meaningless owing to the very low ^{137}Ce concentrations and to the high fixation buffer power in soil ($b_2 = 10^4$). Thus, we conclude that the root turnover does not contribute to uptake.

Kinetic parameter determination.

One of the methods of generating nutrient uptake data is the nutrient depletion method of Claassen and Barber (1974). To propose an analytical and alternative method, we consider the differential problem for the depletion curve (Claassen and Barber, 1974), which is given by:

$$\frac{dC(t)}{dt} = -A \left[\frac{J_m C}{K_M + C} - E \right], \quad C(0) = C_0$$

with $A = l/V$ where l is root length and V is the volume of nutrient solution. By integration we obtain:

$$Bt = G \left(\frac{(J_m - E)C(t) - EK_M}{(J_m - E)C_0 - EK_M} \right), \quad B = \frac{(J_m - E)^2 A}{(J_m - E)C_0 - EK_M}$$

and real function G is defined by:

$$G(x) = 1 - x - D \log x, \quad 0 < x < 1, \quad D = \frac{K_M J_m}{(J_m - E)C_0 - EK_M}$$

By using the following properties:

$$G(0^+) = +\infty, \quad G(1) = 0, \quad G'(x) < 0, \quad 0 < x < 1$$

and the real inverse function $F(x) = G^{-1}(x)$, defined for

$x > 0$, which satisfies the properties

$$F(0^+) = 1, \quad F(+\infty) = 0, \quad F'(x) < 0, \quad \forall x > 0$$

then we get the following explicit expression for the concentration versus time:

$$C(t) = \frac{EJ_m}{J_m - E} + \left(C_0 - \frac{EK_M}{J_m - E} \right) F(Bt), \quad t > 0$$

Now, from the depletion curve $C = C(t)$, are obtained the following experimental data:

$$C'(0) = -\alpha, \quad \alpha > 0, \quad C''(0) = \beta, \quad C(\infty) = \gamma$$

These data are related with the efflux E , the maximum influx at infinity concentrations J_m and the Michaelis-Menten K_M constant through the following analytical relations obtained from the expression for $C(t)$ shown above, i.e.:

$$\alpha = A \left[\frac{J_m C_0}{C_0 + K_M} - E \right], \quad \gamma = \frac{EK_M}{J_m - E},$$

$$\beta = \frac{A^2 K_M J_m}{(C_0 + K_M)^3} [(J_m - E)C_0 - EK_M]$$

Solving the system of three equations for the unknown E , J_m , K_M we obtain the following expressions for E , J_m and K_M .

$$E = \frac{\alpha}{E \left[\frac{\beta C_0}{\alpha^2} \left(\frac{C_0}{\gamma} - 1 \right) - 1 \right]}, \quad K_M = \gamma \left[\frac{\beta C_0}{\alpha^2} \left(\frac{C_0}{\gamma} - 1 \right) - 1 \right]$$

$$J_m = \frac{\gamma \beta}{A \alpha} \left[\frac{\beta C_0}{\alpha^2} \left(\frac{C_0}{\gamma} - 1 \right) - 1 \right] \left[\frac{\left(\frac{C_0}{\gamma} - 1 \right)^2}{1 - \frac{\beta \gamma}{\alpha^2} \left(\frac{C_0}{\gamma} - 1 \right)} \right]$$

We have applied our method to experimental data extracted from Claassen and Barber (1974) and the following results were obtained (Table 2):

Table 2. J_m , K_M , E parameters computed by Claassen-Barber method and our method

Parameter	Claassen-Barber	Our method
J_m (pmol cm ⁻¹ s ⁻¹)	4	3.077
K_M (mol cm ⁻³)	27	21.9
E (pmol cm ⁻¹ s ⁻¹)	0.18	0.518
k ($=J_m/K_M$) (cm ² s ⁻¹)	4.014×10^{-4}	3.918×10^{-4}

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