Root Phenotyping with Root Modeling: Towards Sustainable Rice Production

著者	TAJIMA Ryosuke
journal or publication title	Journal of Integrated Field Science
volume	15
page range	48-50
year	2018-10
URL	http://hdl.handle.net/10097/00124002

JOURNAL OF
INTEGRATED FIELD SCIENCE
Field Science Center, Graduate School of Agricultural Science, Tohoku University

Symposium paper

Root Phenotyping with Root Modeling: Towards Sustainable Rice Production

Ryosuke TAJIMA

Field Science Center, Graduate School of Agricultural Science, Tohoku University, Yomogida, Osaki, Miyagi, 989-6711, Japan

Keywords
modeling, phenolyping, rice, root system

Corresponding Author
Ryosuke TAJIMA, tazy@tohoku.ac.jp

Abstract

Improving root system architecture (RSA) has a huge potential both on crop production and environmental impacts. To improve RSA, we need to deeply understand RSA but it is extremely difficult to determine a few root phenotypes. In this review, we proposed to analyze the phenotype of RSA using root model: one is with datasets from lab-based experiments and the other is with limited datasets from field observations. First, we could predict RSA in the field even at the end of the growth season with data in the paper culture at the early growth stage. Second, we could predict the parameters which can't be measurable in the field from field observations. These approaches could be potentially powerful techniques for identifying the root phenotypes.

Introduction

Root system architecture (RSA) in rice production system has been shown to be important both for production and environmental impacts. Improving RSA increases resource acquisition, especially in low-input conditions. For example, Uga *et al*. (2013) found a *DEEPER ROOTING1* (*DRO1*) gene making the growth angle of nodal root larger. Introducing *DRO1* gene to IR 64 which has a shallow root system, the introduced plant relatively had a deeper root system and higher yield performance under drought condition than IR 64. Increasing resource acquisition also leads to decrease the resource loss to groundwater and reduce irrigation and fertilizers, which links to mitigate environmental impacts. In addition, improving RSA could have a potential to increase carbon stocks in the soil. The output from root (root exudates and root decompositions) in the growth season and the remains of root after yielding are major carbon sources. Increasing carbon from root could enhance soil organic carbon. As a result, it would reduce atmospheric CO_2 concentration. In Paustian *et al*. (2016), the mitigation effects per hectare of improving RSA estimates larger than that of biochar application and the applicable area of improving RSA estimates as large as that of management practices.

To improve RSA, we need to deeply understand RSA: the performance of root phenotypes and their interactions in the whole root system from seeding to yielding under the various field conditions. However, it is extremely difficult even to determine some root phenotypes. Even to estimate partial root length density at only one growth stage, the process is back-breaking, time-consuming and often to need many workers.

Here, for getting over the process with less effort, we propose to analyze the phenotype of RSA using root model which simulates RSA to understand it in the field.

Root model description

Root models have been developing from the 1970s with developing and generalizing computers and the associated equipment. In Dunbabin *et al*. (2013), six current root models were introduced but almost all models could not be used without the collaboration with the developers. Currently, a few root models are becoming open-source, but it has been difficult to say that the models are easy to use for the potential users yet. Therefore, I'm developing another root architectural model named Seurat (Simulator for evaluating and understanding root architecture). In rice, root system consists of one seminal root and numerous nodal roots which are generated from the stem. One nodal root consists of parent root and numerous lateral roots which are generated from the parent root. Each seminal, nodal and lateral root consists of many cells but, in Seurat, a mass of cells sets as a dot and each root presents as a troop of dots. The dots have various parameters, such as elongation rate, diameter, gravitropism and position, which are updatable depending on endogenous and ectogenous factors such as age and environment.

Running Seurat needs the basic information of nodal roots and the parameters of individual roots. The basic information of nodal roots is easily measurable in both laboratory and field because the information is estimated with observation of basal part of the rice plant. The basic information of nodal

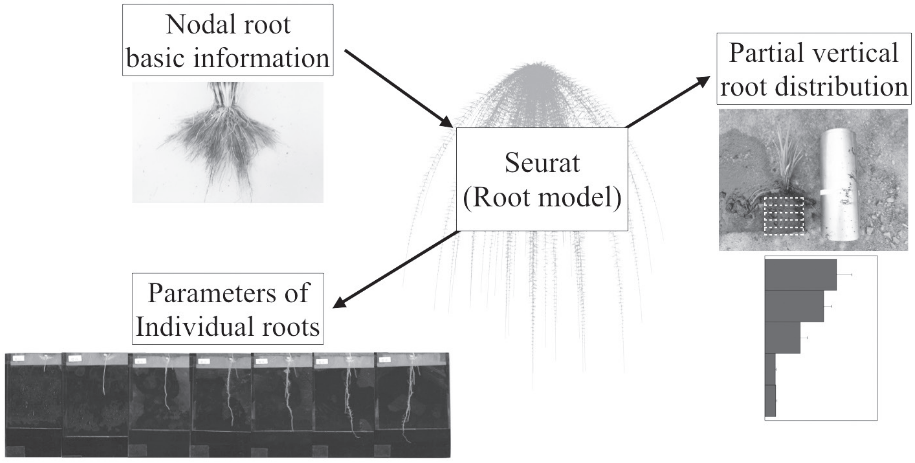

Fig. 1. The outline of root phenolyping with root model.

roots consists of the time of nodal root emergence, vertical and horizontal growth angle of each nodal root. The nodal root emergences could be controlled by several rules, therefore, if the rules become clearer than now, it could be easier to set nodal root information. On the other hands, it is difficult to measure the parameters of individual roots directly. Therefore, we should get the parameters in lab-based experiments or predict the parameters from field observations using Seurat.

Phenotyping with root model

In this review, I introduce two ways for phenotyping root system using root model: one is with datasets from lab-based experiments and the other is with limited datasets from field observations.

1) Using laboratory-based experiments

I predicted RSA with the datasets of the parameters of RSA at the early growth stage of rice plants in the laboratory-based experiment. Some lab-based experiments such as paper or soil cultures against transparent plates allow for non-destructive and time-lapse observations on individual plants. These experiments could take a large amount of photo with less work. According to my experiment, the root grew between paper and transparent plates. I took the images at several times with an image scanner. This paper culture provided various data by analyzing time-lapse two-dimensional images. In my results, running root model with the datasets of this laboratory-based experiment, I could predict RSA in the field even at the end of the growth season. And I suggested a little bit difference of traits at very early growth stage might become a large difference of root system at the end of the growth stage in the field. However, there is concern that the conditions with laboratory-based experiments don't simulate field conditions, e.g. the observed roots that grow against plates in the paper culture could not be similar to that in the soil. On the other hands, in laboratory-based experiments, root box is more similar to field conditions than paper culture because of using soil, but it is harder to measure root traits than paper culture.

2) Using field observations

I predicted the parameters of RSA which can't be measurable in the field with the field observation. I used the basic information of nodal roots and the data of nodal root partial vertical distribution in the soil at a one growth stage. Nodal root number and growth angle which easily identified from the observations around the basal part were used as the information of nodal roots. In nodal root distribution, we took the cylinder soil monolith (10cm diameter) located just under the rice plant in less than 10cm soil depth. This is monolith method which is one of the old but standard methods. This soil monolith with roots was divided into five layers. These parts were carefully washed and nodal root length was measured with image analysis (Tajima and Kato 2011, 2013). Using these datasets, we attempted to predict the parameters of individual nodal roots, the elongation rate and gravitropism, with Nelder-Mead method which is a commonly-used nonlinear optimization method. As a result, we could find the parameters through the procedure. However, it's very preliminary result because, in this trial, taking root distribution at only one time was too limited to predict the accurate parameters of RSA. If we can collect more data which has already existed such as vertical root distribution taken in old but standard methods like the monolith method, more realistic RSA could be predicted.

Summary and Outlook

I proposed the model-based approach for phenotyping in root system with datasets both from laboratory-based experiments and field observations (**Fig. 1**). Using root model with laboratory-based datasets at early growth stage could predict the RSA at later growth stage in the field. In addition, using root model with the limited datasets of partial root distribution at one growth stage in the field might estimate the several root phenotypes which have been extremely difficult to measure in the field. These approaches could be potentially powerful techniques for identifying the root phenotypes. The data of phenotype identified using root model can be relatively easily acquired. These big datasets could develop root modeling. Thus, there is a mutually complementary relationship between root phenotyping and modeling. Developing this relationship should accelerate to propose a groundbreaking RSA ideotype and contribute RSA improvement for boosting up rice production and reducing environmental impacts in the future.

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