Journal of Theoretical Biology 403 (2016) 59–67

Contents lists available at ScienceDirect

Journal of Theoretical Biology

journal homepage: www.elsevier.com/locate/yjtbi

Genetic algorithm based approach to optimize phenotypical traits of virtual rice

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HIGHLIGHTS

- We report a method based on GA and FSPM model to optimize plant types of virtual rice.
- Phenotypical traits are considered as input parameters of our virtual rice model.
- The photosynthetic output is used to evaluate each individual plant type's quality.
- The experimental results explain the effectiveness of the proposed method.

ARTICLE INFO

Article history:
Received 11 October 2015
Received in revised form
29 April 2016
Accepted 2 May 2016
Available online 11 May 2016

Keywords:
Functional-structural model
Genetic algorithm
Plant type
Optimal design

ABSTRACT

How to select and combine good traits of rice to get high-production individuals is one of the key points in developing crop ideotype cultivation technologies. Existing cultivation methods for producing ideal plants, such as field trials and crop modeling, have some limits. In this paper, we propose a method based on a genetic algorithm (GA) and a functional-structural plant model (FSPM) to optimize plant types of virtual rice by dynamically adjusting phenotypical traits. In this algorithm, phenotypical traits such as leaf angles, plant heights, the maximum number of tiller, and the angle of tiller are considered as input parameters of our virtual rice model. We evaluate the photosynthetic output as a function of these parameters, and optimized them using a GA. This method has been implemented on GroIMP using the modeling language XL (eXtended L-System) and RGG (Relational Growth Grammar). A double haploid population of rice is adopted as test material in a case study. Our experimental results show that our method can not only optimize the parameters of rice plant type and increase the amount of light absorption, but can also significantly increase crop yield.

1. Introduction

The qualities of a rice plant's type and canopy structure play key roles in increasing its production and improving its quality. Therefore, more and more scientists in this area focus on the problem of optimizing phenotypical traits of rice in order to obtain ideotype individuals with high or super-high production.

Two main strategies are used to investigate ideotype breeding (Qi et al., 2010; Andrivon et al., 2013): 1) the experiment based approach (Peng et al., 2008; Srbislav 1994); and 2) the plant model based approach. For the first approach, the breeding experts implement numerous test-cross-screenings on crop plants in the field and then carefully observe, analyze, and summarize their phenotypical traits. Finally, ideotypes can be obtained after long term breeding and observation. Although this method can find an optimal plant type close to the ideotype we want, it is time-consuming and difficult to verify whether the cultivated plant types achieves the optimal shapes or not (Su et al., 2008). In addition, this approach takes little consideration of environmental and other random factors which have influence on the growth of plants. The other method of finding a crop ideotype, the plant models-based approach (Yin et al., 2003; Cilas et al., 2006; Markus et al., 2007; Letort et al., 2008; Suriharn et al., 2011; Milo and Last 2012; Semenov et al., 2014; Van Oijen and Hoglind, 2016) can more accurately describe the relationship between the growth and

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http://dx.doi.org/10.1016/j.jtbi.2016.05.006
0022-5193/

development of plants and environmental factors. Using this method to study plant growth behavior not only compensates for the shortage of field experiments, but also saves time and resources. However, the method does not contain the morphological information of plants, so it cannot be used to study the relationship between plants and the environment by combining it with a three-dimensional morphology method. Therefore, it is necessary to explore a new method for cultivating the ideotype crop.

Considering the above problems and previous research, we propose a method based on a genetic algorithm (GA) and a functional-structural plant model (FSPM). This model has the ability to optimize virtual rice by dynamically adjusting its phenotypical traits. A plant functional-structural model effectively combines the structures of plants with their physiological functions, and can quantitatively simulate the growth and development of plants and make the whole process visible (Lu et al., 2014; Room et al., 1996; Sarlikioti et al., 2011a, 2011b). In this model, through the calculation of photosynthetic yield in a crop canopy, the assimilation in different organs and their final productions, we can obtain the phenotypical traits of a rice plant which can maximize the amount of light radiation intercepted and the grain yield.

As an effective optimization method, the genetic algorithm (Qi et al., 2010; Quilot-Turion et al., 2012; Drewry et al., 2014) has been applied in some complicated optimization problems of different plant types and achieved good results. Our virtual rice model is built according to the principle of a plant functional-structural model. In this model a genetic algorithm is employed to study how to optimize the parameters of rice plant type, such as leaf inclination angle, plant height, maximum tiller number, and tiller angle. The new model provides a method for developing a crop ideotype.

2. Functional-structural model of rice

A rice plant is made up of roots, stem, leaves and panicles, as shown in Fig. 1. The jointed stem of the rice consists of a series of nodes and internodes. The composition of a rice panicle includes panicle axis, primary and secondary branch, and spikelet (before maturity)/grain (after maturity). Rice plants have three growth stages: 1) vegetative (from germination to panicle initiation); 2) reproductive (from panicle initiation to flowering); and 3) ripening (from flowering to mature grain). For more information about the rice plant, please refer to the literatures Sharma and Singh (1999) and Moldenhauer et al. (2002).

The Functional-structural model described in this article is constructed using the eXtended L-System modeling language (XL) (Kniemeyer, 2004) on an open-source platform, GroIMP (Kniemeyer et al., 2008). XL is developed based on the Java programming language, and further integrated with the parallel rewriting rules of the L-system (Kniemeyer et al., 2004). GroIMP is an interactive platform for virtual plant development, including model construction, visualization, interactive modules, etc. Using grammars of the XL language and the Java programming language, a model of virtual plant can be constructed based on various rules and algorithms.

The rice FSPM integrates physiological processes, morphogenesis rules, and related environmental parameters together in one model. It is capable of simulating the dynamics of the production and consumption of biomass based on several models, i.e. the photosynthesis model with parameters of leaves and intercepted light calculated based on topological and geometric information, the carbon partitioning model with prediction of source-sink relations, and the growth model with organ formation and morphogenesis processes (Xu et al., 2009).

The structural part of the rice FSPM describes the process of the plant morphological construction and development of the stems, grains, and leaf blades. A cylinder is used to simulate one internode, and multiple connecting internodes made a stem or a spikelet. A grain is constructed using a curved surface and texturing. Furthermore, an instance variable *j* is designed within each leaf object, indicating the amount of intercepted light, which is a key factor in influencing the assimilation rate and the amount of photosynthetic yield. Detailed descriptions of the structural model can be found in articles of Xu et al. (2009, 2011).

There are five main modules contained in the rice FSPM: the light environment module, the radiation model, the photosynthesis model, the carbon partitioning model, and growth functions for organs.

2.1. Light environment module

In the light environment module, direct and diffuse light radiation components are established to simulate the distribution of light in the sky. The former is solar radiation directly reaching the Earth's surface in the form of a parallel solar beam, while the later is solar radiation being scattered after passing through the atmosphere. The sky is simulated as a set of light sources (Evers et al., 2010; Buck-Sorlin et al., 2011) which represent light with different light intensity from different positions. Rays emitted by all light sources are uniformly distributed parallel rays, and uniformly put into the scene. Stocking density is controlled by the number of rays, and the respectively formulae of the direct radiation E_{dir} (W/m^2) and diffuse radiation E_{dif} (W/m^2):

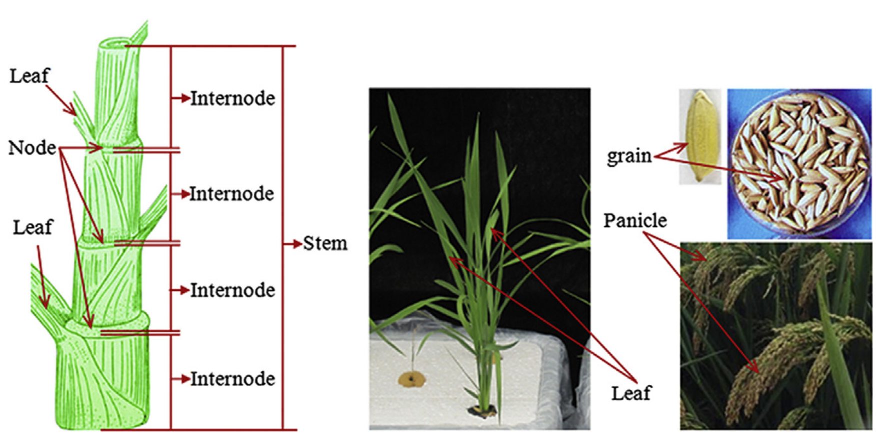

Fig. 1. the organs of rice plant.