Research on Digital Construction of Crop Plant Type Based on a Kind of Improved Functional-Structural Model and Component Technology

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Abstract. Taking digital construction of crop ideotype as the target, current functional-structural model was improved, which discussed the biomass production, biomass allocation and organ reconstruction, the division of crop organ components and the way of component connections was put forward, and the internal structure of the components was explored to leaf organs as an example. At last, the process of digital construction of crop plant type was elaborated, which laid foundation for the plant type quantitative design.

Keywords: functional-structural model, componentization, crop plant type, digital construction.

1 Introduction

Botanical studies have shown that crop plant type has an important influence on crop yield[1,2]. By improving the spatial structure characteristics of crop, the access efficiency of the plant to light, water and other resources can be improved, thus, crop photosynthetic production can be distinctly increased, but traditional plant type breeding experiment is a long cycle, high cost and subject to the natural environment. With the deepening of research on virtual crop, quantitativly creating the plant type to meet the special requirements becomes a possible way to solve the above problem. To some extent, crop life activities characterize a result of the interaction between crop morphology, physiological and ecological processes and environment[3], so in order to reflect the objective reality of crop growth process, parallel simulation of crop structure and function must be carried out[4], thus one of the basic problems of using virtual crop technology to construct ideotype is the establishment of the crop functional-structural model.

In common crop functional-structural model, as shown in Figure 1, after the completion of the biomass production and allocation, only carrying on morphological reconstruction of shape factor of plant organs, such as organ length, width and area,

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but now organ not only occured morphological changes, there were the relative changes of the position and inclination, especially the leaf inclination angle has great significance on plant getting energy. Thereby, in the process of organs reconstruction, only to consider the shape factor will affect the proper biomass production and allocation of the next growth phase of organ, so that it will make greater degree of distortion compared with the reality of crop morphology.

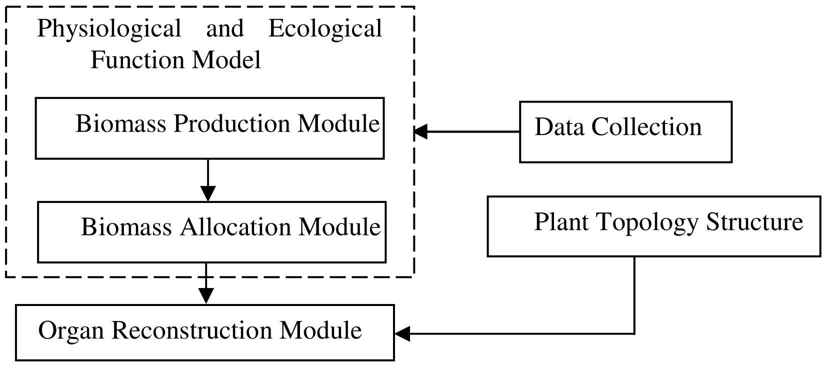

Fig. 1. Functional-Structural Model of Crop

2 Improved Functional-Structural Model

Aming at the defects of current functional-structural model, by summary of organ location factors and the horizontal, vertical variation laws, and real-time control of the dynamic changes in plant growth, morphological reconstruction of the crop plant was achieved in the way of functional-structural mutual feedback, as shown in Figure 2.

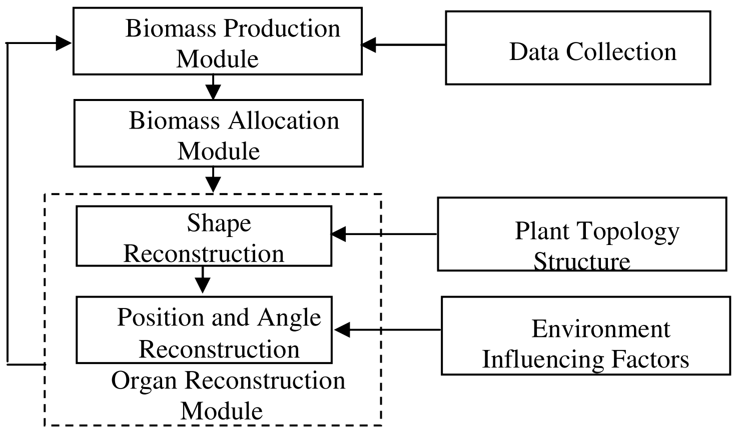

Fig. 2. Improved Functional-Structural Model

2.1 Biomass Production Module

From the perspective of biomass consumption, the produced biomass *M(t)* was studied in the No. t unit growth cycle by using the crop transpiration, structure composition and hydraulic resistance in the body [5].

$$M(t) = \sum_{i=1}^{N(t)} \frac{Energy(t)}{\frac{r_1}{Area(i,t)} + r_2} \tag{1}$$

Here, *Energy(t)* refers to the growth potential of fresh material under the control of water potential differences between inside and outside crop body and water use efficiency in the No. t growth unit cycle; *N(t)* refers to the number of leaves which are able to do photosynthesis in the No. t growth unit cycle; *Area(i, t)* refers to the area of the leaf with the serial number of i in the No. t growth unit cycle; r_1 refers to the hydraulic resistance of the leaf; r_2 refers to the total hydraulic resistance of the other parts except the leaf. However, some parameters of the model (such as *Energy(t)*, r_2) are difficult to measure.

From the energy conservation principle, combined with crop photosynthesis, the calculation method of crop biomass production was studied. [6]:

$$\int_{M_1}^{M_2} dM = \frac{1}{\sigma}\int_{t_1}^{t_2} r(1-g)(1-\lambda)\,I\,dt \tag{2}$$

Here, M_1 and M_2 represent the amount of crop dry mater at time t_1 and time t_2 respectively; σ is the energy released by burning one gram of dry matter; r is the solar energy use ratio per unit green leaf area; g is the crop respiration rate; λ is reflection leakage rate of radiation which is projected on crop plant; I is the surface radiation intensity. Based on the parameters of crop morphological characteristics (for example leaf area index, leaf azimuth), the biomass *M(t)* produced by the photosynthesis in the No. t growth unit cycle can be calculated.

2.2 Biomass Allocation Module

Botanical studies have shown that, in the process of transporting and distributing biomass to the organs by vascular, the transmission path has few impact on the distribution, which depends on the type of organ. Different organs (such as leaves, petioles, stems) have different competitiveness of biomass (usually represented by sink strength) and different expansion rates of themselves. The sink strength s of the organ can be defined as the coefficient of thermal ages [7]; expansion rate m is generally consistent with beta probability density function [8]. If the growth age of an organ is set as y (set the growth cycle as the unit), then the expansion amount of this organ in the No. t growth unit cycle is:

$$\Delta M(y,t) = \frac{s(t)m(t-y+1)}{\sum s(t)(\sum_{i=1}^{t_0} m(t-i+1)})M(t-1) \quad (3)$$

Here, *s(t)* refers to the sink strength of an organ in the No. *t* growth unit cycle; *t-y* refers to the actual growth age of the organ; t_0 refers to the number of organ expansion cycle.

Therefore, the total biomass *M(y, t)* of the organ with the growth age of *y* in the No. *t* growth unit cycle is:

$$M(y,t)=M(y,t-1) + \Delta M(y,t) \quad (4)$$

2.3 Organ Reconstruction Module

Based on biomass allocation, various organs, through the obtained biomass, completed the crop secondary growth or formed other new organs. Current software with powerful data analysis functions (such as Matlab) can be used to analyze the fresh weight, morphological factors, growth position and angle of the collected organs, and the data are conducted fitting by least squares or other methods, obtaining the intrinsic relationship between the fresh weight, morphology factors(such as organ length, width), location and angle to establish the function-structure coupling and morphology controllable model.

3 Components of Crop Organs

Based on object-oriented programming, further abstraction is made in the component design idea. The basic idea is to split the complex system into components according to the functions, forming component module in small scale with unitary function[9]. Component is consisted of interface and implementation body. The implementation body can be accomplished by different technologies, and the interface defined by platform-independent language is the only way for the component to interaction with the outside[10]. In the study of virtual plants, different species and different varieties of the same species may have totally different software designs. Component-based mode can unify the design mode of virtual plant software, making it consistent in structure, so it becomes a necessary condition to digitally construct crop plant type[11].

From morphologically, the crop is composed of roots, stems, leaves, fruits and other organs. Aming at corresponded organs and their growth position, morphological component modules can be built, and the components are connected according to the dependencies on the growth of crop organs, as shown in figure 3.

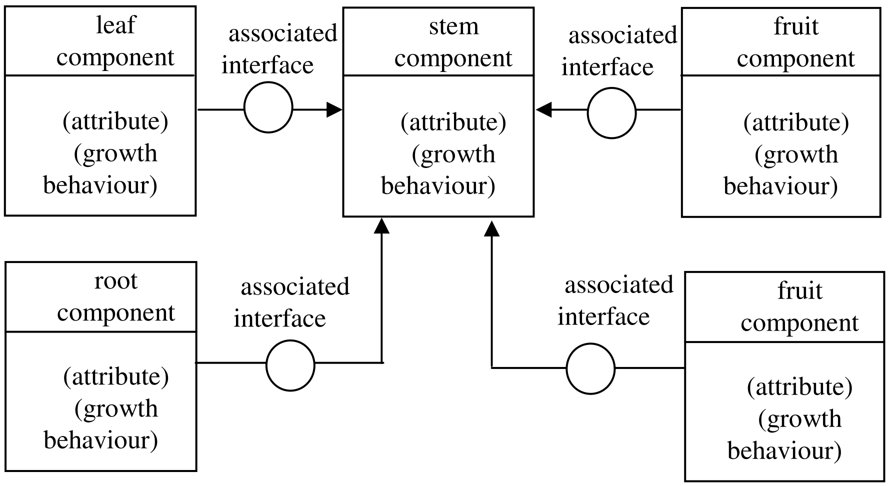

Fig. 3. Component-based organ module division and connection

The internal structures of the component modules for various organs are similar, including basic attribute structure of the organ morphology, growth behaviour (i.e., dynamic process of the growth) and associate interfaces with the other organ components or the system, here, take leaf for example, its internal structure is as shown in table 1.

Table 1. Inner Structure of Leaf Organ Component

Attribute	Behaviour	Interface
Initial growth time	Contour growth (length array, width array, time)	Location interface of leaf growth
Growth duration		Environment component interface
End of growth time	Growth duration = End of growth time − Initial growth time	Visualization component interface
Growth cycle		Expert system component
Leaf length array	Iteration number = Growth duration ／ Growth cycle	User interaction interface
Leaf width array		……
Current vein string	Current vein string = Vein initial string array + Iterated string array×Iteration number	
Vein initial string array		
Iterated string array		
Iteration number	……	

4 Digital Construction of Crop Plant Type

Through using Fourier equation to analyze crop canopy, achieving function description of canopy leaves quantities; Through using extinction equation to simulate light transmittance distribution in canopy, the optimal values of the parameters (such as leaf area index) was obtained and the mathematics model of the production biomass was established. And then, building the crop biomass allocation model according to the measured data of crop biomass and the organ sink strength in experiment, by analysis of the impact of environmental factors on crop morphology, crop functional-structural models of various organs were built, based on the theory of growth equation and combined with a controlled modeling method. On the basis of the above studies, crop ideotype was digitally constructed by components of the various crop organs, shown as figure 4.

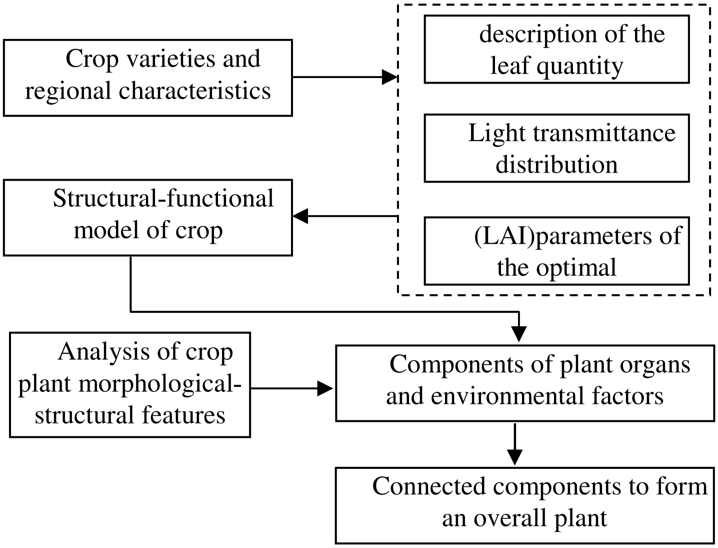

Fig. 4. Digital construction of plant type

5 Discussion

Combined with virtual crop theory and computer software development, digital design method is proposed on crop plant type, trying to achieve quantitative design of plant type to solve problems such as traditional plant type breeding inaccurate. This method is part of the process in the theoretical design stage, its effectiveness depends on the further improvement of the crop structural-functional model and organ components of the degree of precision, future research needs to be carried on to find problems and perfect the methods in the specific environment.

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