DEVELOPMENT OF A MODEL-BASED DIGITAL AND VISUAL WHEAT GROWTH SYSTEM

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Abstract: Driven by soil, variety, weather and management databases and integrating process-based growth simulation model, morphological model and visualization model, a model-based digital and visual wheat growth system (MDVWGS) was developed using component-based software and visualization techniques. The system was programmed by the .Net framework with the language of C# and CsGL Library was used for realizing 2D and 3D graphics application and visualization. The implemented system could be used for predicting growth processes and visualizing morphological architecture of wheat plant under various environments, genotypes and management strategies, and has the functions as data management, dynamic simulation, strategy evaluation, real-time prediction, temporal and spatial analysis, visualization output, expert consultation and system help. The MDVWGS should be useful for construction and application of digital farming system and provide a precise and scientific tool for cultivar design, cultural regulation and productivity evaluation under different growing conditions.

Key words: Wheat; Growth model; Morphological model; Functional- structural plant model; Visualization

1. INTRODUCTION

Crop modeling based on ecophysiological processes of plant growth and development has become an important field of research during the past decades. The main emphasis in crop growth modeling has been put on developing models by description of fundamental biophysical, biochemical and physiological processes of growth and yield formation (Bouman et al., 1996; van Ittersum et al., 2003). This type of models is commonly referred to as process-based models, while plant architecture is normally addressed in a simplified manner. In recent years, approaches have been developed to describe the geometric structure of plant. L-system or similar approaches were used to simulate the architecture of plants (de Reffye et al., 1988; Prusinkiewicz and Lindenmayer, 1990), and these models gained in versatility and provided with graphical capability.

A new modeling approach named functional- structural plant model (FSPM) concerned with integration of architecture and resource allocation as aspects of plant function was developed in the mid 1990s (Godin, 2000; Sievanen et al., 2000). For agricultural crops several reports have been published during the last years dealing with FSPM under development (Drouet and Pages, 2003; Fournier et al., 2003; Hanan et al., 2003; Yan et al., 2004). This type of model incorporates the physiological processes into the architecture model, aiming at 3D geometric structure of plant become mechanism and process-based. But most of these models link an architecture model with a canonical mathematical model (Renton et al., 2005), thus these models can simulate only a few ecophysiological processes.

Many crop growth model-based decision support systems have been established, such as APSIM (McCown et al., 1996), DSSAT (Jones et al., 2003) and GMDSSWM (Pan, 2005), which can simulate crop growth and development with different management strategies and making reasonable decisions about crop management based on the results of crop growth simulation. On the other hand, plant architecture software as AMAP (Jaeger M and de Reffye P, 1992; Godin, et al., 1997) and vlab (Federl and Prusinkiewicz, 1999) integrating computer graphics aim at plant architecture modeling and visualization. So far both crop simulation and decision support and architecture visualization remain to be incorporated into one system or software for a comprehensive representation of crop growth system.

The present study developed a digital and visual wheat growth system in order to gather different eco-physiological modules and visualization techniques for (i) simulating eco-physiological processes as development, growth, yield and quality and making reasonable decisions about crop management (ii) simulating topological and 3D structure of wheat at organ, individual, population levels; (iii) demonstrating the real-time visualization of wheat growth responses to different growth conditions and varieties.

We hereafter achieved the above objectives by integrating a process-based comprehensive growth simulation model WheatGrow (Yan, 1999; Liu, 2000; Pan, 2005), architecture model WheatArch (Cheng, 2004, Tan, 2006) and visualization model for producing a new functional-structural model WheatFM. This included linking the functional processes of

WheatGrow with dynamic structures of WheatArch, as well as integrating component-based software and computer graphic technology for visualization.

2. OVERALL STRUCTURE OF MDVWGS

The MDVWGS could simulate growth, architecture, yield and quality of wheat growing on a uniform area of land under prescribed or simulated management as well as under the changed soil water and nitrogen conditions. It is comprised of database, models, applications and interface (Fig. 1).

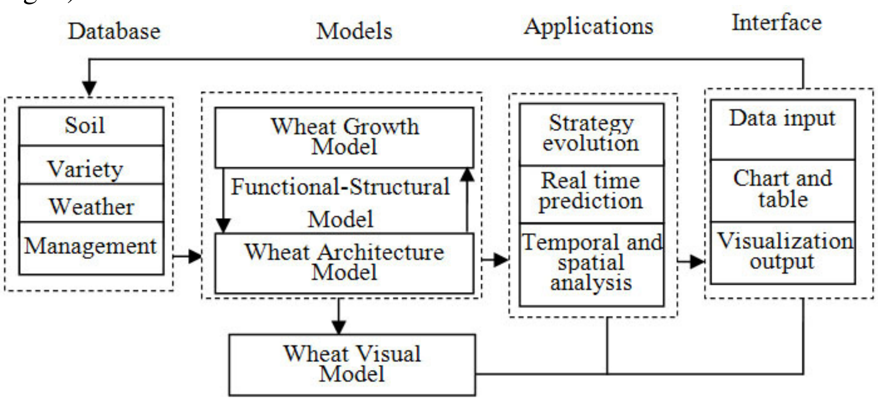

Fig.1: Structural framework of MDVWGS

2.1 Database

The database includes weather, soil, variety and management data. The weather data has daily records of date, maximum and minimum air temperature, sunshining hours and rainfall. The soil data has typical soil parameters for soil module, e.g. soil water content, ammonium N and nitrate in soil layers, thickness of a layer, actual number of soil layers. The variety data includes genotype-specific parameters, e.g. variety name, phenological parameters, thousand-seed weight and parameters of architecture model. Management data contains some common practices of wheat management.

2.2 Models

The main models include growth simulation model WheatGrow, the architecture formation model WheatArch, visualizaton model, and module for model integration.

2.2.1 Growth simulation model WheatGrow

WheatGrow is a field scale, weather-driven, process-based dynamic simulation model (Yan, 1999; Liu, 2000; Pan, 2005), which operates with a daily time-step, including 6 submodels for simulating phasic and phenological development, morphological and organ formation, photosynthesis and dry matter accumulation, yield and quality formation, soil water relation and dynamic nutrient (N, P, K) balance.

2.2.2 The architecture model WheatArch

The architecture model WheatArch allows dynamic construction of geometric structure of actual wheat plant, which can simulate the geometrical and topological structure at organs, individual and population levels in relation to growing degree days (GDD), including topological structure, leaf morphology (leaf length, width, angle and curvature), sheath and internode (width, length), spike (length, width) sub-models and three-dimensional structural model (Cheng, 2004, Tan, 2006).

2.2.3 Integration of WheatGrow and WheatArch

The WheatGrow runs continuously and independently driven by data of weather, variety, soil and management, simulating the functional processes of wheat and providing basic input for WheatArch model. The model WheatGrow was used to calculate: (1) phasic and phenological development to control the runtime of WheatArch from emergence to maturity; (2) characters of population architecture; (3) assimilate accumulation and partitioning, e.g. WheatGrow provides leaf area and leaf weight, while WheatArch simulates individual leaf initiation and growth, and both would be linked to build process-based leaf morphological model (4) water and nutrient factors for quantifying the limiting factors of water and NPK nutrients for WheatArch. These were taken as the inputs of WheatArch.

2.2.4 Visualization model

Visualization model includes geometry, texture, illumination submodels. Geometric submodel includes simulation of several organs, using different geometric shapes (e.g. cylinder) to model leaf, stem and spike; the texture model is constructed by using the photos of organs at different stages with reality as textures and integrated with geometric model; illumination model in OPGL is adopted for simulating the illumination effect in the reality.

2.3 Applications

Different types of applications were accomplished in MDVWGS by using different functions on a daily basis, such as temporal and spatial analysis, strategy evaluation and real time prediction.

2.4 Interface

The interface of MDVWGS included the initial data input, digital and visualization output. The results of simulation strategy in digits can be represented by chart and table, and the results also can be displayed by visualization through the computer graphic technology, including scene controlling as zoom in or zoom out, changing the point of view.

3. FUNCTION DESCRIPTIONS

In MDVWGS, Multiple functions as simulating time-course processes of growth and development, architecture, yield and quality formation, soil water and nutrient dynamics under various environmental conditions, production levels and genetic parameters were developed so that the system could realize the functions of dynamic simulation, strategy evaluation and real time forecasting which have been implemented by Pan(2005) (Fig. 2). Result of these functions can be displayed by digits and visualized as computer images.

4. SYSTEM IMPLEMENTATION

The system was operated under windows 2003 server on PC with 1G of RAM and AMD althon 2500+.The MDVWGS applied Access 2003 to designing database, C# in the framework of .NET to programming the interface and programming growth model components based on the COM standard. Visualization model is designed by CSGL (C sharp Graphics Library) which implements a wrapper for the powerful C-library OpenGL allowing use of any .NET language.

4.1 System display

Part of system application is presented as follows, including the interface of MDVWGS for main menu (Fig. 3 a), digital results displayed by table (Fig. 3 b), the visual output of dynamic individual plant growth (Fig. 3 c, d).

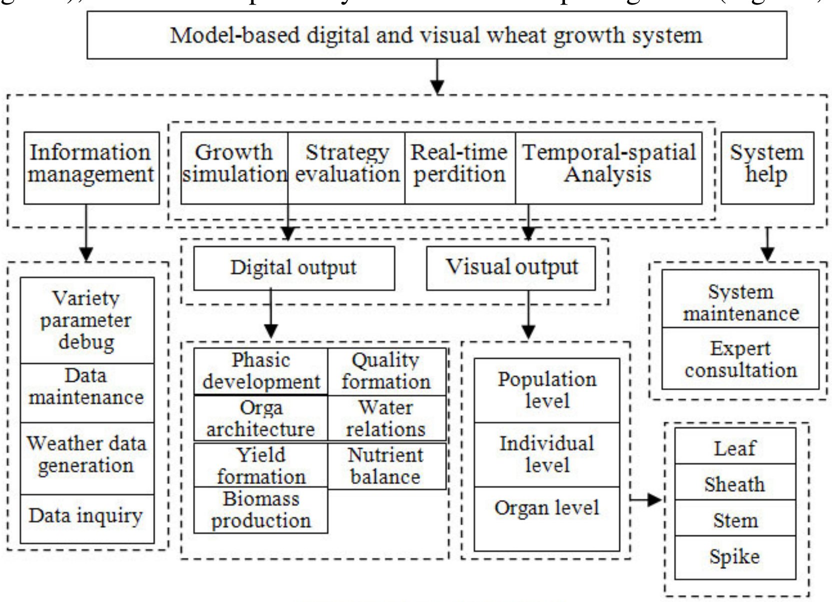

Fig.2: Functions of MDVWGS

5. DISCUSSIONS

Based on a process-based growth simulation model WheatGrow, architecture model WheatAM and visualization model, a digital and visual wheat growth system (MDVWGS) was developed using component-based software and visualization techniques, which enable ecophysiologists to investigate the interaction of organs, single plants or plant stands with their biotic and abiotic environment in a unique way. The implemented system integrated prediction function and decision support function, can simulate eco-physiological processes as development, growth, yield and quality, the structure of wheat dynamics in mechanism and make decisions for mamagement, demonstrate the visualization of wheat growth under various environments, genotypes and management strategies, which providing a precise and scientific tool for cultivar design, cultural regulation and productivity evaluation under different growing conditions.

Systems like MDVWGS would be put into potential for applications of this technology in research, decision support, education and extension (Room, et al., 1996). In order to make the system more applicable and stability, the next steps will be: (1) to incorporate more physiological processes in the model to enhance the application of the model, e.g. calculation of radiation interception and inter-plant competition which would be feedback to growth model; (2) to extend the variety, soil and weather database, so that the system could be used in further comprehensive conditions; (3) to incorporate the root architecture model and visualization into the MDVWGS; (4) to link the MDVWGS with GIS, RS and management knowledge model for using in precision and digital farm.

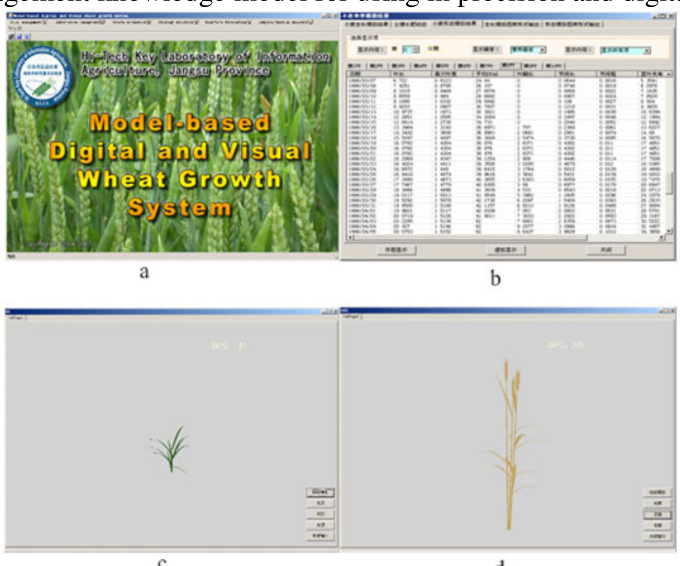

Fig. 3: system exhibition of interface for main menu (a), table output (b), visual output (c, d)

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