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RESEARCH ARTICLE

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Development of a growth model-based decision support system for crop management

Abstract A growth model-based decision support system for crop management (GMDSSCM) was developed, which integrates process-based models of four different crops—wheat, rice, rape and cotton—and realized decision support function, thus facilitating the simulation and application of the crop models for different purposes. The individual models include six sub models for simulating phase development, organ formation, biomass production, yield and quality formation, soil-crop water relations and nutrient (N, P, K) balance. The implemented system can be used for evaluating individual and comprehensive management strategies based on the results of crop growth simulation under various environments and different genotypes. A stand-alone edition ($GMDSSCM^A$) was established on VC++ and VB platforms by adopting the characteristics of object-oriented and component-based software and with the effective integration and coupling of the growth prediction and decision-making functions. A web-based system ($GMDSSCM^W$) was then further developed on the .net platform using C# language. These GMDSSCM systems have realized dynamic prediction of crop growth and decision making on cultural management, and thus should be helpful for the construction and application of informational and digital farming system.

Keywords growth model, decision support system, stand-alone edition, web-based edition

1 Introduction

Dynamic crop simulation models are being used more frequently as research and educational tools and to assist in making management decisions. Crop simulation models have become more comprehensive and applicable since the 1970s (Cao and Luo, 2000). Many crop model-based decision support systems have been established, such as GOSSYM/COMAX (Mckinion et al., 1989), APSIM (McCown et al., 1996) and MODCROP (Waldman and Richman,1996) and DSSATC (Jones et al., 2003). These systems can simulate crop growth and development with different management strategies and make reasonable decisions about crop management based on the results of crop growth simulation. However, they are relatively weak in terms of comprehensive simulation of a crop-soil system and component-based programming technique, which limit their predictability and flexibility to meet different user needs.

The present study developed a growth model-based decision support system for crop management (GMDSSCM) with four crop simulation models of wheat (Yan, 1999; Liu, 2001), rice (Meng, 2002), cotton (Zhang, 2003) and rape (Tang, 2006). The system can be used for simulation trials with different cultural options and for recommending proper management strategies. The GMDSSCM adopted the characteristics of object-oriented and component-based software, including a stand-alone edition ($GMDSSCM^A$) on the platform VB and VC++, and a web-based edition ($GMDSSCM^W$) on the platform of .net with the language of C#. The two different editions were established to meet the needs of different users.

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2 Overall structure of GMDSSCM

The GMDSSCM simulated growth, development, yield and quality of a crop growing on a uniform area of land under prescribed or simulated management as well as under changing soil water and nitrogen conditions. It is comprised of a database, models, applications and interface (or browser) (Fig. 1).

2.1 Database

The database includes two kinds of data: common data and temporal data. The former covers weather data, soil data, variety data, and management data and crop knowledge. The weather data have daily records of date, maximum and

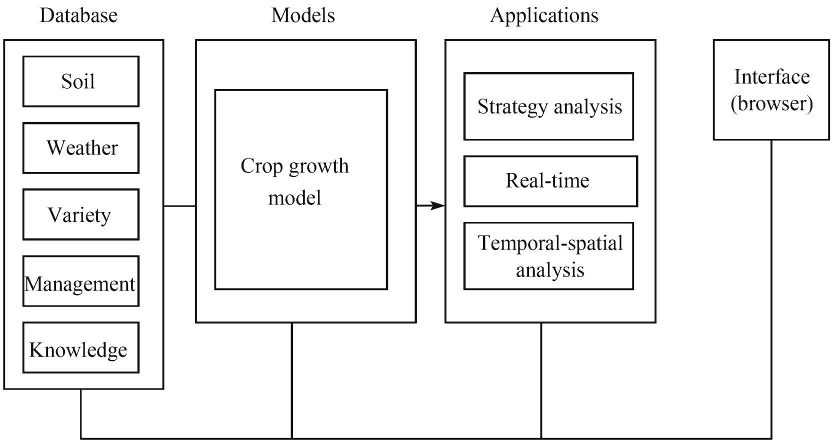

Fig. 1 Layout and flow of system design

minimum air temperature, sunshine hours and rainfall. The soil data have typical soil parameters for a soil module, while variety data include genotype specific parameters. Finally, management data and crop knowledge encompass the results of GMDSSCM and the data of user input. The database can be added, deleted and queried. Microsoft Access and Microsoft SQL Servers were separately adopted by GMDSSCM^A and GMDSSCM^W.

2.2 Models

There are four different crop growth models of wheat, rice, rape and cotton, and each includes six sub models for simulating phasic and phenological development, morphological and organ formation, photosynthesis and dry matter accumulation, yield and quality formation, soil water relation and matter accumulation and dynamic nutrient (N, P, K) balance.

2.3 Applications

Different types of applications were accomplished in GMDSSCM by using different functions on a daily basis, including strategy analysis, real-time prediction and spatial-seasonal analysis.

2.4 Interface (browser)

The user interface (browser) was very simple to allow easy operations by crop consultants. The user can provide the input and read the results of GMDSSCM via mouse and shortcut keys. And the user can also get help from the system through a net service.

3 Function descriptions

In GMDSSCM, simulating functions such as time-course processes of growth and development, yield formation, quality formation, soil water and nutrient dynamics in crop growth system under various environmental conditions, production levels and genetic parameters were developed so that the system could realize dynamic simulation, individual and comprehensive management evaluation, spatial and seasonal analysis (Fig. 2), and provide a framework for the development of a digital crop growth system and decision support system for crop management.

3.1 Data management

The data management consists of three functions: debugging the parameters of variety; creating new weather data on the basis of historical weather data; and inputting variety, weather and soil data in the typical sites and years.

3.2 Dynamic simulation

The dynamic simulation was used to run crop growth model components based on the COM standard, access the database, input data from the interface and then read the data and diagrams of results from the growth model, including time-course variables involved in the processes of phasic and phonological development, morphology and organ formation, photosynthesis and dry matter accumulation, soil water and nutrient dynamics as well as yield and quality formation.

3.3 Strategy evaluation

Several strategies were quickly simulated by the system that gave the user some suitable management options in the typical site and anticipated circumstances. Among them, individual management strategy served as the function of separately conducting simulation experiments of variety, density, sowing date, fertilization and irrigation by the system. This approach could recommend the optimum individual management option via comparing and analyzing the simulation results.

And comprehensive management strategy integrated the individual management practices including variety, density,

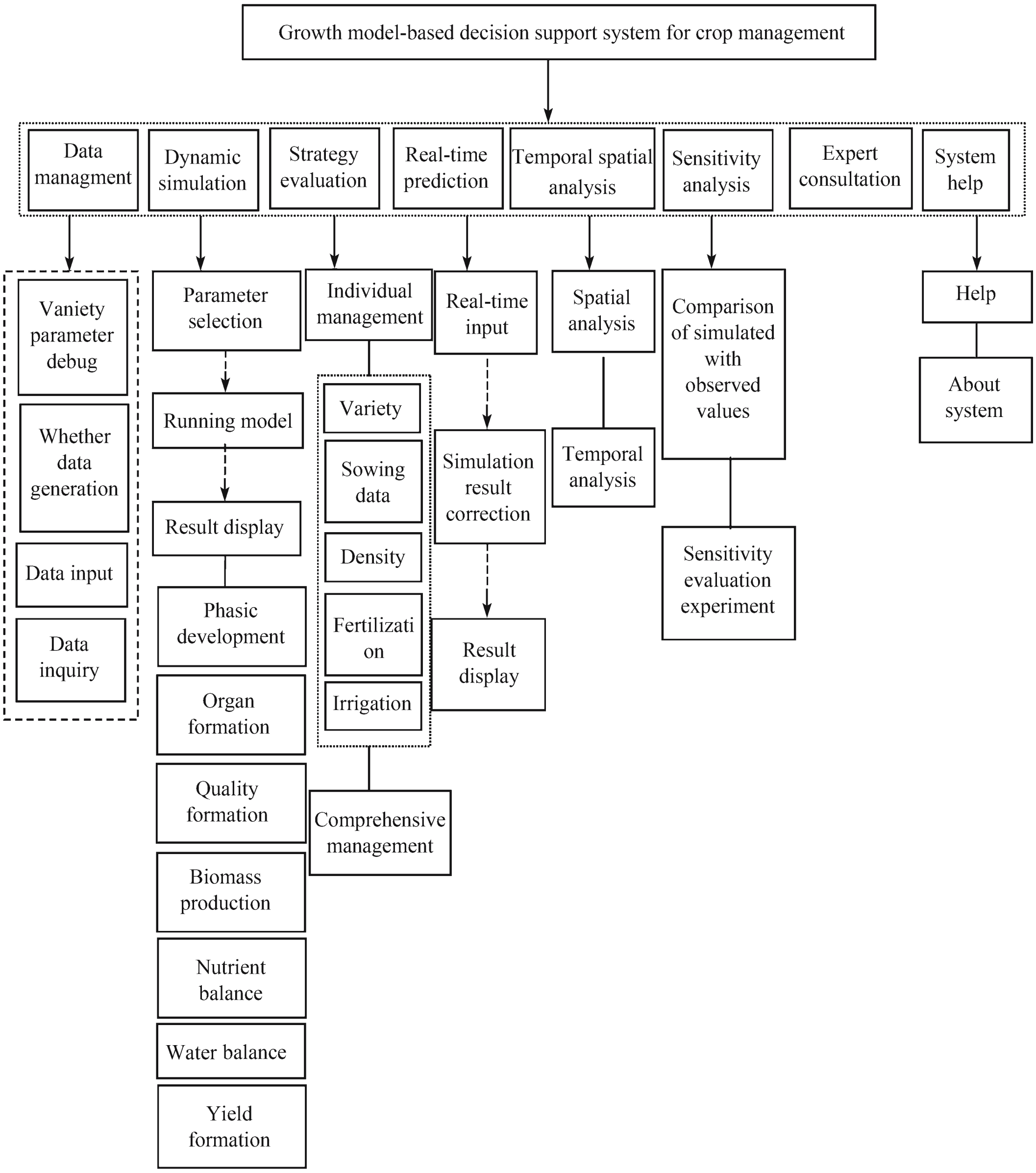

Fig. 2 Functional diagram of GMDSSCM

sowing date, fertilization and irrigation so as to recommend a comprehensive management plan for decision-making.

3.4 Real-time prediction

This function was used to help the user simulate real-time growth status obtained at a given growth stage from observation and monitoring by inputting the data via interface. If there was more than a 5% difference between user input and model simulation, real-time growth data would start to correct output from the system, which would continue running the model according to the corrected growth status. Finally, two types of output results were displayed. The system selected leaf area index and dry matter accumulation as standard growth indicators, because they were the two main determinants of yield formation in field crops.

3.5 Temporal and spatial analysis

This function has two operational modes—temporal analysis and spatial analysis. The former was to simulate crop growth over a number of years of weather data under the same initial soil conditions to evaluate the effects of uncertain future weather conditions on crop performance and decision options when all initial soil conditions are known. The other mode was to simulate one or more crops under different spatial conditions to make a spatial difference analysis in precision agriculture and land use management or realize other space-based applications in the system.

3.6 Expert consultation

With a comprehensive introduction of crop production in the sub-system, this function was to enable the user to get expert consultation and technical support from the sub-system that was filled with multimedia information that includes crop growth and development, irrigation, fertilization, pest management, and nutrient diagnosis.

4 System implementation

The system was operated under Windows 2000 server on a PC with 1 GB of Random Access Memory (RAM) and AMD Athlon 2500+. Pentium II, 64 M of RAM and the Windows 98 operating system were the minimum requirements.

4.1 Stand-alone edition (GMDSSCM^{A})

The GMDSSCM^{A} applied Access 2000 to design the database server, Visual Basic 6.0 to program the interface and Visual C++6.0 to program growth model components based on the Component Object Model (COM) standard. This design is convenient for system maintenance and updates (Dai, 2001).

4.1.1 Input system implementation

Data input is an important part of the system. Database technology was applied to resolve the data input and output problems.

4.1.1.1 Database design

A large amount of data are needed for the system, the datum structure of which is different. For example, the structure of weather data is relatively simple, but the number of weather data is relatively big; yet the number of soil data is small and the structure is relatively complex. Thus, data were classified by data structure and type. The weather table has more records and fewer fields, while other tables have more fields and fewer records. Every table is associated with the code of "site + year + trial".

4.1.1.2 Database validity check

The system permits the user to input data into the database. Once some data were input, the system would check if they were valid. When the data were invalidated, an error information would be displayed on the interface instructing the user to input valid data.

4.1.2 Output system implementation

The output, including simulation and decision support information, would be displayed to the user by interface. The simulation result would be saved to the database and read by the output system, which increases the system's adaptation and flexibility.

4.2 Web-based edition (GMDSSCM^{W})

Based on the three-layer web structure of "web browser / application server/database server" (Sun, 2001), GMDSSCM^{W} separated the application server into the application procedure server and Web server according to system application logic and function. Thus, GMDSSCM^{W} practically adopted the four-layer web structure of "web browser/Web server/ Application server/Database server" (Fig. 3). It is convenient for system maintenance and updates because each layer is independent, i.e. modification of a certain layer would not influence others.

Web server was designed for response to the requests of a client sever, delivering the requests to the data server and application server, putting the results of data inquiry and simulation in HTML files, and finally sending them to the client browser. The data server was designed as the database of GMDSSCM^{A} in the structure, which served as the function of communicating with application server and web server via ADO.NET. The application server consisted of crop growth simulation, picture and text information and decision support strategies in design.

The GMDSSCM^{W} was developed on the platform of .net with the language of C# and the techniques of object-orientation, COM+ component and web application. Microsoft SQL server was used to design database and VC++ .net was adopted to program growth model components.

5 Conclusions

Based on the crop growth simulation model and strategy evaluation method, a growth model-based decision support system for crop management (GMDSSCM) was established by adopting the characteristics of object-oriented and component-based software with non-language relevance, re-utilization and portable system maintenance. The implemented system includes two different editions for wheat, rice, rape and cotton. It can be used for predicting the performance of a crop growth system and evaluating different management strategies under various environments and genotypes. Compared with current decision support systems, the GMDSSCM has several outstanding features as component-based system design, integration of the prediction function and decision support function, single or multiple field crops. Two editions of stand-alone and web-based are for different user needs. On-going studies are focused on linking the GMDSSCM with Geographic information system (GIS), Remote Sensing (RS) and management knowledge model for use in precision farming and digital farming.

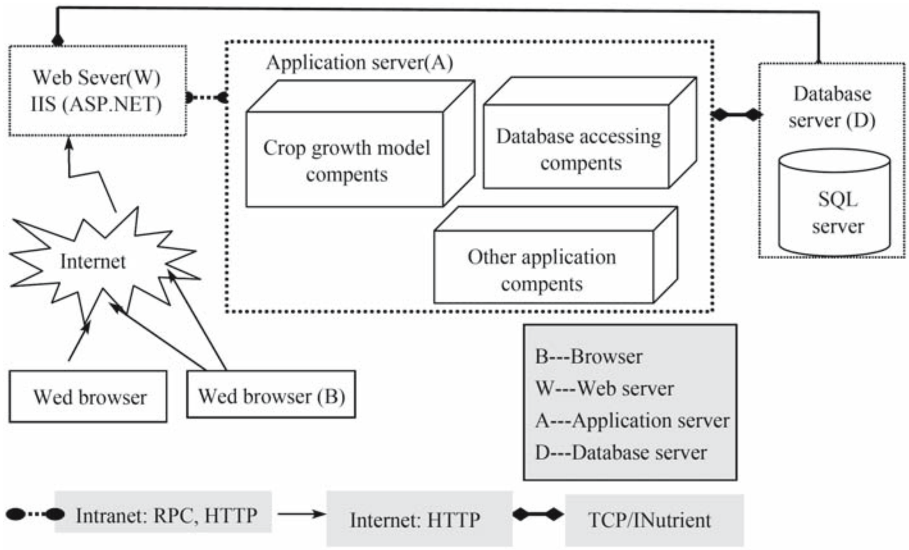

Fig. 3 Four-layer web structure of GMDSSCM^{W}

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