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A Knowledge Model System for Wheat Production Management*[1]

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ABSTRACT

A knowledge model with temporal and spatial characteristics for the quantitative design of a cultural pattern in wheat production, using systems analysis and dynamic modeling techniques, was developed for wheat management, as a decision-making tool in digital farming. The fundamental relationships and algorithms of wheat growth indices and management criteria to cultivars, ecological environments, and production levels were derived from the existing literature and research data to establish a knowledge model system for quantitative wheat management using Visual C++. The system designed a cultural management plan for general management guidelines and crop regulation indices for time-course control criteria during the wheat-growing period. The cultural management plan module included submodels to determine target grain yield and quality, cultivar choice, sowing date, population density, sowing rate, fertilization strategy, and water management, whereas the crop regulation indices module included submodels for suitable development stages, dynamic growth indices, source-sink indices, and nutrient indices. Evaluation of the knowledge model by design studies on the basis of data sets of different eco-sites, cultivars, and soil types indicated a favorable performance of the model system in recommending growth indices and management criteria under diverse conditions. Practical application of the knowledge model system in comparative field experiments produced yield gains of 2.4% to 16.5%. Thus, the presented knowledge model system overcame some of the difficulties of the traditional wheat management patterns and expert systems, and laid a foundation for facilitating the digitization of wheat management.

Key Words: expert system, knowledge model, quantitative decision-making, regulation index, wheat

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INTRODUCTION

Development of expert systems and decision support systems has provided new tools for crop management in modern farming (Jones, 1989; Plant and Stone, 1991; Bouman *et al.*, 1996; Cao, 2000). During the past 20 years, many expert systems for agricultural production management have been developed using knowledge engineering and artificial intelligence (Lemmon, 1986; Jones, 1989; Goodell *et al.*, 1990; Chai *et al.*, 1994; Zhao *et al.*, 1997; Xiong *et al.*, 1999). Wide application of these expert systems to agricultural decision-making has generated social, ecological, and economic benefits (McKinion *et al.*, 1989; Ma, 2000). The performance of the expert systems in management decision-making relies heavily on the capacity of knowledge rules as a core base of the expert system. In traditional expert systems, the knowledge rules often contain a large number of qualitative and semi-quantitative expert experiences and empirical parameters with site- and time-specific characteristics (Goodell *et al.*, 1990;

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Plant and Stone, 1991; Chai *et al.*, 1994; Zhao *et al.*, 1997; Xiong *et al.*, 1999). Because of this basic feature, the expert systems are well adapted to local environment and production conditions, but when extrapolated to wider circumstances they perform poorly. This shortcoming has limited the adaptation and accuracy of the traditional expert systems under diverse environmental conditions (Zhu, 2003).

Meanwhile, crop growth simulation models, such as CERES-Wheat (Ritchie and Godwin, 1988) and AFRCWHET (Porter, 1993) for wheat, and CERES-Rice (Singh *et al.*, 1993) and ORYZA2000 (Bouman *et al.*, 2001) for rice, have achieved notable success in knowledge integration and system prediction and have provided a dynamic decision-making tool to support evaluation of varied management strategies in crop production. Through system analysis and mathematical modeling, crop simulation models can quantitatively describe and dynamically predict the processes of crop growth and development in response to various environment and production factors (Bouman *et al.*, 1996; Sinclair and Seligman, 1996; Cao and Moss, 1997; Cao and Luo, 2003). These simulation models can only predict the possible outcome of systems operation under a given set of conditions, but cannot directly provide optimum decisions on crop management (Cao and Luo, 2003). In other words, the simulation models seem to be complementary to the expert systems in terms of the prediction function *vs.* decision-making function. Thus, if the system modeling methodology was used to integrate and quantify the knowledge base in crop management, this would help to develop a quantitative management model or a modeled expert system for dynamic decision-making in crop production, and would replace the knowledge rules and inference engine in the traditional expert systems with a quantitative model. This approach would overcome the difficulties of traditional cultural patterns and expert systems, such as specific site limitation, a massive knowledge base, and low quantification, and lay a foundation for facilitating dynamic decision-making on crop management and for further constructing a new digital farming system by incorporating other subsystems (Liang *et al.*, 2003). Thus the present study aimed to quantify knowledge system for crop production management in wheat, using systems analysis and dynamic modeling. The objectives were to develop a knowledge model with dynamic characteristics for quantitative design of management plans and regulation indices in winter wheat by extracting the general relationships and algorithms of management techniques and growth dynamics to cultivars, ecological environments, and production levels, and then to establish a computerized knowledge model system or a modeled expert system to support winter wheat management with the programming language Visual C^{++}.

MATERIALS AND METHODS

Model system development

The boundary, components, and environment were first defined with the concept of systems analysis. The cultural management plan and crop regulation indices were two groups of basic structural components or target variables for the design of cultural patterns in a wheat production system. These two groups of system components were affected by the driving variables in the system environment, including cultivars, climate factors, soil conditions, and production levels. As these driving variables exhibited obvious temporal and spatial variations under diverse conditions, cultural techniques and growth indices would correspondingly change with the driving variables. This implied that decision-making in crop production management must be made on the basis of quantification of dynamic relationships of cultural techniques and growth indices to the multiple driving factors in the crop production system. Building such a knowledge model for dynamic wheat management should be done on the basis of the methodology for modeling the management knowledge base and digitalizing the farming system.

Data acquisition for the development of the knowledge model was mainly from four sources: 1) literature including research achievements, monographs, books, periodicals, and publications in scientific meetings on wheat physiology, ecology, and management, along with the records of soils, cultivars, and weather data; 2) collaborating scientists in related research areas; 3) supplemental experiments or support research; and 4) research accumulation, experience, and knowledge from the authors' group during the last 20 years. Data from the first and the fourth sources were used mainly for development