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RESEARCH ARTICLE

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Knowledge model-based decision support system for maize management

Abstract Based on the relationship between crops and circumstances, a dynamic knowledge model for maize management with wide applicability was developed using the system method and mathematical modeling technique. With soft component characteristics incorporated, a component and digital knowledge model-based decision support system for maize management was established on the Visual C++ platform. This system realized six major functions: target yield calculation, design of pre-sowing plan, prediction of regular indices, real-time management control, expert knowledge reference and system administration. Cases were studied on the target yield knowledge model with data sets that include different eco-sites, yield levels of the last three years, and fertilizer and water management levels. The results indicated that this system overcomes the shortcomings of traditional expert systems and planting patterns, such as site-specific conditions and narrow applicability, and can be used more under different conditions and environments. This system provides a scientific knowledge system and a broad decision-making tool for maize management.

Keywords maize, knowledge model, expert system, decision support system

1 Introduction

The development of crop simulation models and expert systems has provided new means for crop production management modernization and communization (Cao, 2000). Crop decision support systems based on models or expert knowledge and other integrated key technologies have been used extensively worldwide, bringing major benefits to society, the economy and ecology (Jones and Kintry, 1986; Cao, 1997; Liao, 2000; Liu, 2000; Jones et al., 2003; Bhargava et al., 2005). Representational crop management decision support systems based on simulation models include the DSSAT system in the US (Jones et al., 2003) and the RCSODS system of Jiangsu Province (Gao and Jin, 1992). Although such systems have strong system integration and dynamic prediction, they cannot be used for actual decision-making directly because they require high parameter precision and are limited by poor maneuverability (Gao and Jin, 1992; Jones et al., 2003). Crop management decision-making support systems, based on expert knowledge expression, provide the so-called "Expert system of wheat cultivation management" (Zhao et al., 1997) and "Expert system of cotton cultivation management" (Dong and Han, 1996). They embody the preferred computer abilities of reasoning and solving problems except rich expert experiences and parameters of strong site-specific data and timeliness, low quantification level, narrow applicability and non-forecasting, which limit their application and veracity in different places and conditions (Dong and Han, 1996; Liu, 1997; Zhao et al., 1997; Bie et al., 2001). By applying the system analysis method and mathematic modeling technology to a knowledge expression system of crop management, a knowledge model of crop management was established in Nanjing Agricultural University (Cao and Luo, 2003). The model is helpful in integrating merits of the crop simulation system and expert system, achieves organic coupling and a comprehensive unification of dynamic prediction and management decision, and provides a basis for precision and digital in crop management (Cao and Luo, 2003; Cao and Zhu, 2004). A management decision-making support system based on knowledge model of wheat, cotton, and rape has already been established (Cao and Luo, 2003; Zhang and Cao, 2003; Zhu et al., 2004a; Zhu et al., 2004b), but none yet for maize.

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2 Materials and methods

Applying the system analysis principle and mathematic modeling technology, resolving and extracting the basic connection and quantitative arithmetic of the relationship between maize growth and management indices to cultivars, environmental factors and production levels, a knowledge model for maize management was developed on a PIII733CPU platform, 128 M EMC memory computer, and Windows 2000 in Chinese. This was then combined with soft-component technology, yielding a knowledge model-based decision support system of maize management (KMBDSSMM) on Visual C++.

2.1 System framework and content

The system mainly includes a database, a knowledge model base, an expert knowledge base and an interface (Fig. 1).

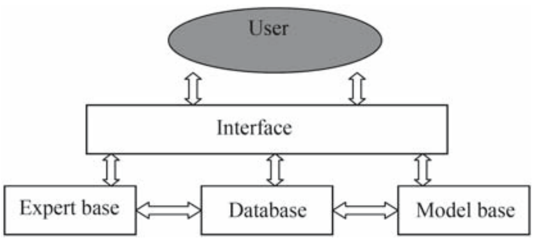

Fig. 1 Framework of KMBDSSMM

2.1.1 Database

The system database includes the following ones. (1) A district database providing geographic information on the name and latitude and longitude of maize zone provinces in northern and eastern China. (2) Environmental database providing weather and soil property data. Weather database covers daily data from the year 1994 to 2000 in different eco-sites (provided by Ground Weather Monthly in China); soil database stores data on soil section (provided by the National Engineering Research Center for Information Technology in Agriculture). (3) Cultivars database providing cultivar property information referred to in the handbook “Maize cultivars examined and approved nationwide”, the characteristics in morphology and physiology of which came from experimental results, literatures and the Internet. (4) Cultivation management database providing the routine management levels of maize, including the earliest eco-site sowing dates, the latest reaping date, and water and fertilization management levels. (5) Diagnostic database providing support for system real-time water and fertilizer control and mainly storing stem and leaf nutrient content indices (N, P, K) and suitable soil water content indices at different growth stages. (6) A social economic database providing related information on farm machine, water conservancy, labor, fertilizer, pesticide and seed expenditure and grain yield price.

2.1.2 Knowledge model database

The knowledge model database showed a quantitative relationship among maize cultivation condition, production target, growth and management indices and environmental factors. Establishment of the model led to cognition, conception, formalization, realization, and testing stages (Guo et al., 2005) (Fig. 2).

The system includes five submodels: target yield calculation, design of pre-sowing plan, prediction of main regulation indices, real-time management control and production economic benefit analysis. Among them, the design of pre-sowing plan consists of submodels of cultivar selection, sowing date decision, population density and sowing rate, fertilization strategy and water management. The prediction of main regulation indices includes four submodels of suitable leaf age indices development, colony leaf area indices dynamic, colony dry matter accumulation curve and source-sink indices as a ratio of total grain number or grain weight to leaf area. In terms of analysis of production benefit, expenditure of labor, material and financial resources throughout the whole growth process, yield and price of maize are included.

2.1.3 Expert knowledge database

The complexity of crop development systems made it difficult for us to learn and quantify different parts of a crop system. Therefore, the knowledge model database focuses on the store of technological knowledge that cannot be quantified and expressed in models around maize management to help secure expert suggestions and make precise decisions through the interface. The content includes pre-sowing seed treatment, fertilization principles, sowing technique, field management, water strategy, disease and pest prevention, special cultivar characteristic, cover-film technique and indices of nutrient and water content for diagnosis in different growth stages.

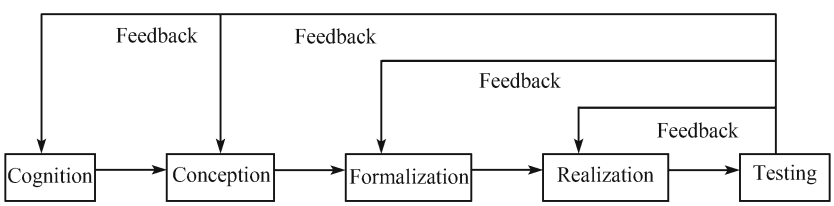

Fig. 2 Process of knowledge model development for maize management

2.1.4 Interface

This system adopted a structure of "model-document-vision" (Mi et al., 2003), integrating a question-and-answer interlocution function, menu technique, language clarity and graphics mode, which make it simpler and user friendly.

3 System function and design principal

The system offers functions such as yield target calculation, pre-sowing plan design, regular indices prediction, real-time management control, expert knowledge browsing and system maintenance (Fig. 3).

3.1 Yield target calculation

Yield target calculation was based on the agriculture ecology zone (AEZ) model (Wang and Han, 1990; Peng et al., 1997). First, it deals with deciding the standard crop dry matter accumulation with radiation and temperature resource. The yield potential of radiation and temperature after quantifying the effect of weather factors (daily temperature, cloudy film degree) and crop parameters (leaf area index, harvest index and growth period time) are covered next. Finally, climate productivity after considering rainfall, fertilization and water management levels, and prevention levels of pests, diseases and weed are considered. The dynamic increment index came from climate productivity compared with the average yield of the last three years, which shows the range of production increment.

3.2 Pre-sowing plan design

The system ran a knowledge model to judge whether the yield target was reasonable with data on weather, soil and cultivar resource in normal years. If reasonable, sets of suitable planting plans will be established on the basis of these submodels (cultivars selection, sowing date decision, density and sowing rate, fertilization strategy and water management).

3.2.1 Cultivar selection

Whether cultivar yield potential could meet a user's expectation was considered first before selection, followed by an estimation of the adaptability of their prematurity to the users' planting period. Finally, the system recommended suitable cultivars to a user on the basis of requirements for resistance, adaptability and lodging resistance.

3.2.2 Sowing date decision

A suitable sowing date should guarantee maize maturity on schedule, making development stages and the best season

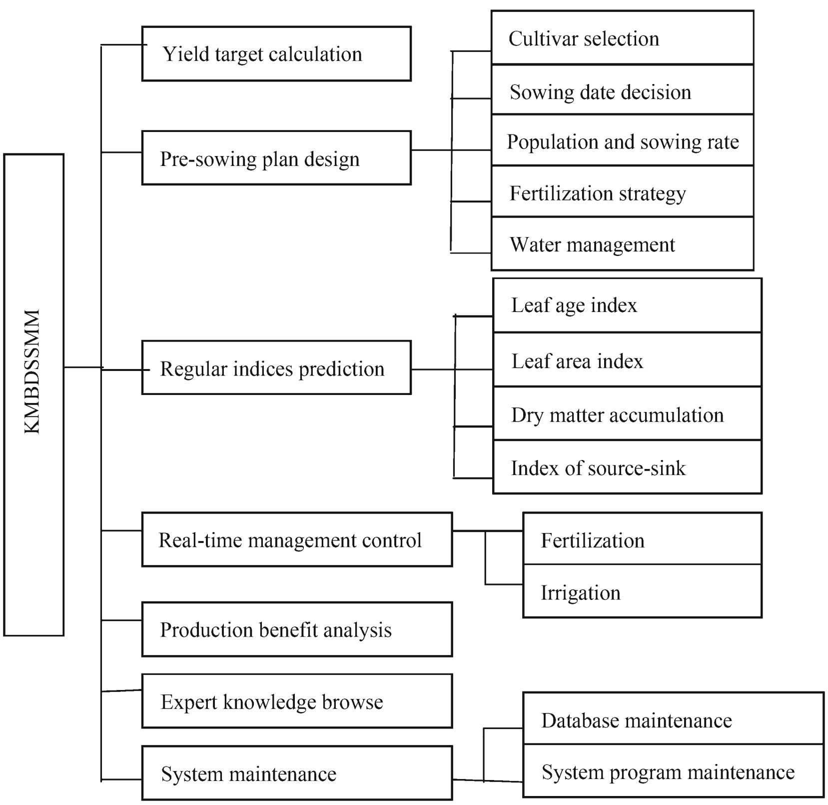

Fig. 3 Functions of KMBDSSMM

in-phase to make the crop reach corresponding growth indices in main stages. The model decided the most suitable sowing-date scope by matching heat-light resource in eco-sites to suitable heat-light requirements in two main growth stages (silking and filling), with the user making a final sowing date decision accordingly.

3.2.3 Population density and sowing rate

Maize is an individual plant with high productivity, with a suitable plant density that can harmonize conflict between individuals and colonies to get high yield. The model was used to decide the suitable population density based on different principles at different soil fertilizer levels. This means that in a high soil fertilizer field, the density should be based on maximum suitable leaf area in silking calculated by light intensity during filling; in the middle and low soil fertilizer field, density should be based on ears from yield target. Suitable sowing rates were then decided with a seeding emergence ratio affected by environmental conditions such as soil temperature, soil bulk density, water content, seed plumpness and sowing quantity.

3.2.4 Fertilization strategy

The fertilization strategy was based on the total rate of N, P, K; the ratio of organic N to mineral N; and the ratio and time of basic fertilizers to topdressing fertilizers. The total rate of N, P and K was calculated by using a nutrient balance model—Stanford equation. The ratio of organic N to mineral N was decided by the yield target, the ratio of basic fertilizer to topdressing fertilizer was based on soil fertilizer levels, and the time of topdressing fertilizer was decided by users according to maize nutrient requirement principles and times of topdressing.

3.2.5 Water management

Water management included the rate and time of irrigation. Based on the soil water balance principle, recommendations were made after considering water content around the maize root in initial stages and telophase, availability of rainfall, field transpiration and water requirement at different growth stages.

3.3 Regular indices prediction

Under certain planting conditions, crop growth, development and production formation have “a reasonable dynamic trend” or “a suitable growth route” which can be reflected by a series of growth indices (Ling, 2000; Lu, 2003). The trend or route provides technology support for quantifying seedling status diagnosis and water and fertilizer control. The system decided on the ideal dynamic of regular indices (leaf age index, leaf area index, dry matter accumulation and source-sink index) in maize growth stages for users, after considering yield target, average yield of the last three years in eco-sites, cultivar characteristics and weather.

3.3.1 Leaf age index dynamic

Including visible leaf age and invisible leaf age, leaf age dynamic was calculated by cultivar physiological heat leaf to leaf (PHYLL), total leaves and environmental condition in an eco-site.

3.3.2 Leaf area index dynamic

The ideal leaf area dynamic should be given a suitable maximum value at the silking stage. The suitable maximum leaf area at that stage was calculated after quantifying yield target, cultivar type, daily light intensity and natural light capture by leaves at shoot base. The leaf area index dynamic was then decided by importing a maize leaf area ebb and flow index equation.

3.3.3 Dry matter accumulation dynamic

Maize dry matter accumulation followed a Logistic equation; dry matter production ability of trump to sucking stage and dry matter accumulation of silking to maturity should be enhanced to get a high yield. Based on the Logistic equation, the dry matter accumulation dynamic concerning yield target and harvest index was decided.

3.3.4 Source-sink index

The source-sink index represents the ratio of total grain number or grain weight to the leaf area, which could be calculated by yield structure, average yield in the last three years and maximum leaf area index at the silking stage.

3.4 Real-time management control

In the process of dynamic management control, quantitative suitable management was the key technique of the system (Ling, 2000; Lu, 2003; Zhu et al., 2004a). Functions of the module are shown in Fig. 4. According to the “expert curve” designed by the knowledge model of regular indices prediction and reason analysis, a suitable control management and implementation time would be given, when real-time seedling status departs from the standard “expert curve” to make the crop development follow the “expert curve” for the whole growth period, otherwise no control management was given. Seedling status should be measured all the time.

3.5 Production benefit analysis

Benefit analysis in the whole growth period was calculated by the difference between input and output. Input factors included manpower, financial investment, and material expenditure, while output factors included maize yield and price. Results could also be printed.

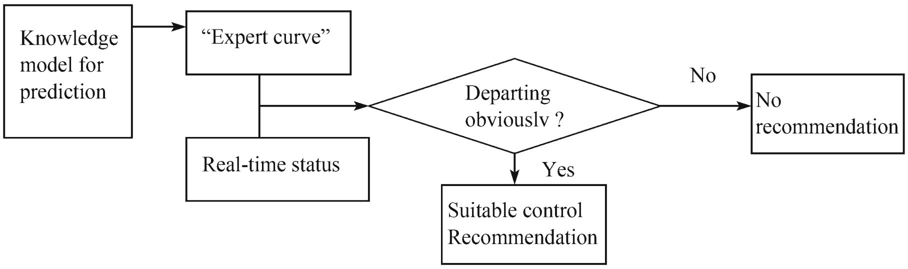

Fig. 4 Flow chart of dynamic control

3.6 Expert knowledge browsing

The expert knowledge database can be browsed and consulted. Vivid pictures and letters can help users in field management and in the prevention of diseases, pests and weed at different growth stages during the whole period of maize cultivation management.

3.7 System maintenance and administration

Different users have different rights and have access to the database by browsing, searching, amending, adding and deleting data if necessary.

4 System exploiture and verification

4.1 Exploiture circumstance and tools

On a PIII 733CPU, 128M EMC memory computer, and Windows 2000 in Chinese, the interface and database management system (DBMS) were designed by using Visual Basic6.0; models and reasoning machine were designed via Visual C++6.0; and the database structure was designed by using Access.

4.2 Verification of the system

Cases were studied on this system with Beijing data sets on normal weather, soil and cultivar characteristics, yield levels of the last three years, fertilizer and water management levels and other factors (Guo et al., 2005). The result indicated that this model has wide applicability and provides a scientific knowledge system and broad decision-making tool for maize management. Verification for the submodel of yield target calculation was conducted in a suite of plan of yield increment and target yields under different yield levels in the last three years, soil fertility, fertilizer and water management levels in different eco-sites during normal climatic years (Table 1, Table 2).

Table 1 shows the average yield levels of the last three years and yield potential under radiation and temperature for different year types in different eco-sites predicted by the model, which followed the same rule of changing trends in radiation and temperature resource and was reduced from Jinan to Beijing and to Shenyang.

Table 2 shows the yield increment and target yields under different yield levels over the same period, soil fertility, and fertilizer and water management levels across the eco-sites during a normal climatic year designed by the knowledge model. Results proved that given the same average yield, soil fertility, fertilizer and water management, yield increment in different eco-sites was positive to differences between average yield levels of the last three years and radiation and temperature potential. However, under the same eco-site, soil fertility, water and fertilizer management, yield increment in different climate years was negative to varying average history yields. Additionally, under the same eco-site and history yield, yield increment was positive to soil fertility and fertilizer and water management. Results of verification indicated that the system offered a good explanation and has wide applications. Yield targets designed by the model under different conditions and cultivation levels tallied well with that of routine schemes at current corresponding eco-sites (Chen and Li, 1994; Song et al., 1998; Ling, 2000; Wang, 2000; Lu, 2003).

5 Conclusions and discussion

Based on the relationship between crops and circumstances, a dynamic knowledge model system for maize management applicable to different places and conditions was developed

Table 1 Average yield levels and yield potential in different eco-sites calculated by the model

Eco-site	Average yield level of last three years/(kg·hm^{-2})			Radiation and temperature potential/(kg·hm^{-2})		
	High level	Middle level	Low level	High year	Normal year	Low year
Beijing	9 750	7 500	5 250	30 028.5	27 093	23 160
Jinan	10 500	8 250	6 000	32 787	29 988	25 174.5
Yulin	9 000	6 750	4 500	27 789	24 925.5	21 051

Notes: Last three years refer to 2001, 2002 and 2003.

Table 2 Results of yield increment and target yields designed by the knowledge model

Water management	Eco-site	Item	High fertility			Middle fertility		
			HY HF	MY HF	LY HF	HF	MY MF	LF
High	Beijing	YI/%	23.6	41.2	78.3	39.4	32.2	25.7
		TGY/(kg·hm^{-2})	12 060	10 590	9 360	10 455	9 915	9 420
	Jinan	YI/%	26.1	44.2	82.3	39.6	31.6	23.4
		TGY/(kg·hm^{-2})	13 230	10 815	9 570	11 520	10 860	9 255
	Yulin	YI/%	20.5	38.7	73.6	37.9	31.5	24.4
		TGY/(kg·hm^{-2})	10 845	9 360	7 815	9 315	8 880	8 400
Middle	Beijing	YI/%	19.3	34.6	60.5	33.0	26.6	18.9
		TGY/(kg·hm^{-2})	11 625	10 095	8 430	9 975	9 495	8 925
	Jinan	YI/%	22.3	35.3	65.4	34.3	27.7	18.8
		TGY/(kg·hm^{-2})	12 840	11 160	9 930	11 070	10 530	9 795
	Yulin	YI/%	14.6	27.4	58.7	31.4	24.8	18.8
		TGY/(kg·hm^{-2})	10 320	8 595	7 140	8 865	8 430	8 010
Low	Beijing	YI/%	15.7	25.9	44.8	25.4	20.4	14.1
		TGY/(kg·hm^{-2})	11 280	9 435	7 605	9 405	9 030	8 565
	Jinan	YI/%	17.6	33.6	59.2	28.9	23.6	12.9
		TGY/(kg·hm^{-2})	12 345	11 025	9 555	10 635	10 200	9 315
	Yulin	YI/%	9.6	18.3	39.4	25.3	17.4	12.3
		TGY/(kg·hm^{-2})	9 870	7 980	6 270	8 460	7 920	7 575

Notes: HY, MY, and LW stand for high yield, middle yield and low yield, respectively; HF, MF, and LF stand for high fertilizer, middle fertilizer and low fertilizer, respectively. YI and TGY stand for yield increment and target yields, respectively.

using the system method and technique of mathematical modeling. A component and digital knowledge model-based decision support system for maize management was established on Visual C++ that integrated soft component characteristics. Compared with other current crop management systems, this system integrated merits of the crop simulation system and expert system, and achieved organic coupling and a strong and comprehensive unification of dynamic prediction and management decision; application of the soft component technique made each module an automatic component in Component Object Mode (COM) standard, which has good independence. The yield target calculated by the AEZ model integrated various factors and conditions of water, energy, and nutrient mineral supply that affected maize production, providing a basis for precise evaluation of production potential at different eco-sites and establishing the effect of climate change to soil production in combination with Geographic Information System (GIS). Although this system has been tested with data sets of different eco-sites, cultivars, soil, and management level (Guo et al., 2006, 2007), it still needs further tests and appraisals at other eco-sites to fully maximize maize management decision-making.

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