Research and application of cultivation-simulation-optimization decision making system for rapeseed (Brassica napus L.)

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Abstract The objectives of this study were to develop Rapeseed Cultivation Simulation-Optimization-Decision Making System (Rape-CSODS), and validate it in order to design rapeseed planting, regulate and control its growth and development, and fulfill its high yield, good quality, high benefits, and standard production eventually. The models in Rape-CSODS were developed based on field experiments with 3 cultivars, 2 plant types, 6 sowing dates, and 4 sites from 2002 to 2008 in the middle and lower valley of Yangtze river in China and relative data from references of rapeseed research, employed ideas of R/WCSODS (Rice/Wheat Cultivation Simulation-Optimization-Decision Making System), then Rape-CSODS were developed through integrating rapeseed growth models, optimization models, and expert knowledge. In that the rapeseed growth models mainly included phenophase, leaf age, population dynamic, and organ forming etc., and the optimization models for rapeseed cultivation mainly included the optimum biomass, the optimum LAI, the optimum shoot and ramification number dynamics models, and the optimum decision making models for nitrogen and water etc. As a case, the system has been applied in Shandong Province in this study, and the results showed that the scheme get by this systems can increase green leaf number before over-winter, 1.1; 1000-weight, 0.2g; and rapeseed yield, 676.5 kg ha^{-1} at mature, comparing with rapeseed production in the same conditions. The Rape-CSODS with general adaptability, clear yield aim, better mechanism, and dynamic characteristic can get the optimum management sheet pre-planting, micro-adjustment sheet during growth for rapeseed under different climates, soil, cultivars, and yielding levels.

Key words: Rapeseed; Cultivation; Growth Models; Optimization Models; Decision Making System; Research and Application

1. INTRODUCTION

Rapeseed is one of four main oil crops in the world, whose plant area is about 14.1million ha in general. In the same time, it is also main oil crops in China, and its plant area is 4.0-5.0 million ha.

The crop simulation and the 3S (GPS, GIS, and RS) technology are the core and foundation of digital cultivation technique systems (Cao *et al*., 2005), and the crop simulation technology mainly included the crop growth models, the optimum models in cultivation, and the simulation-optimization-decision making. In that the optimum models in rapeseed cultivation were mainly the models of the optimum season, population dynamic, seed rate, fertilizer rate, and soil water etc., which set a basis and goals for the simulation-optimization-decision making in rapeseed, and had an important significant in promoting digital cultivation and realizing objective dynamic quantitative and optimum management.

In the world, the research of rapeseed models can be divided into two stages obviously, i.e. the empirical models as main (70-80's of 20 century), and the (partially) mechanism models as main (since 90's of 20 century). In the later stage, the rapeseed growth and development and ecological system models such as EPR95 (Kiniry *et al*.,1983), DAR95 (Peterson *et al*.,1995), LINTUL-BRASNAP (Habekotté, 1997), CERES-rape (Gabrielle *et al*.,1998,1999), APSIM-Canola (Robertson *et al*.,1997), and CECOL (Husson *et al*.,1997) etc. were developed, and they can simulate rapeseed growth and development in real time. However, in China, the research of rapeseed simulation model were not more. Liao *et al*. (2002a, 2002b) studied characteristics of dry matter accumulation, distribution, and transfer of winter rapeseed, and developed the knowledge-based expert system for rapeseed production. Liu *et al*. (2003, 2004) set up simulation model of rapeseed phenophase etc. Zhu *et al*. (2004, 2005, 2007) studied dynamic knowledge model and decision support system for rapeseed cultivation. Cao *et al*. (2006, 2009) carried out the studies of simulation models of phenophase, leaf age, dry matter, leaf area, and ramification numbers. Tang *et al*. (2006, 2007a, 2007b) studied dynamic simulation on photosynthesis and dry matter accumulation, shoot dry matter partitioning, and yield formation of rapeseed, and developed a growth model-based decision support system for rapeseed management. However, few studies have been done on research and application of cultivation-simulation-optimization decision making system for rapeseed.

The objectives of this paper were to establish Rapeseed Cultivation Simulation-Optimization-Decision Making System (Rape-CSODS) through combining the rapeseed growth models, the optimization models for rapeseed cultivation, and expert knowledge for plant diseases and insect pest of rapeseed, apply it in rapeseed production in Liaocheng of Shandong province of China, and validate it in order to design rapeseed planting, regulate and control its growth and development, and to fulfill its high yield, good quality, high benefits, and standard production eventually. In that the models in Rape-CSODS were developed based on field experiments in Yangtz river middle and lower valley of China.

2. MATERIALS AND METHEODS

2.1 Materials

"Zhongshuang 9" (V1, conventional) and "Zhongyouza 2" (V2, hybrid) (breed by Institute of Oil Crops Research, China Academy of Agricultural Sciences, CAAS), and "Ningyou16" (V3, conventional) and “Ningyou18” (V4, conventional) (breed by Institute of Economic Crops Research, Jiangsu Academy of Agricultural Sciences) ,and “Qinyou 2” (V5, hybrid) (breed by Center of Sci-Tech & Education Research of Shaaxi Province) were used in the experiments.

2.2 Methods

2.2.1 Referring to references

Its aims were to apprehend and master the rapeseed growth and development rules and principles of growth regulation and control for rapeseed whole, and obtain initial parameters on varieties, soil, and climates etc. by referring to the references in papers and books on rapeseed physiology, ecology, and cultivation etc.

2.2.2 Development of Rape-SCODS

The Rape-SCODS were established through combining the rapeseed growth models, the optimization models for rapeseed cultivation, and expert knowledge for plant diseases and insect pest of rapeseed using Visual Basic ver. 6.0 and VFP ver. 6.0.

2.2.3 Validation of Rape-SCODS

The scheme get by this systems, Rape-SCODS, were compared with rapeseed production in the same weather, soil, cultivars.

2.2.4 Experiments

In order to decide the parameters of the models and verify the models, the field experiments with different rapeseed cultivar types in multi-sites and multi-years were carried out.

Experiment 1: Two rapeseed cultivars, V1 and V2, were grown in the field from 2002 to 2005 on Red loam soil near Wuhan (soil test in pre-planting results indicated the following: total nitrogen, 1.2 g kg^{-1}; organic matter, 20.7 g kg^{-1}; pH, 7.79; and volume weight, 1.50g/cm^3, 30° 05′N), Hubei Province. The six planting dates were 15 September, 22 September, 29 September, 6 October, 13 October, and 20 October, respectively. The experiment included 12 treatments, 3 replications, and 36 subplots arranged random with 8.00- by 2.50-m. Fertilizing and other field managements in subplots were the same. Fertilizer contained 180 kg N ha^{-1}, 120 kg P_2O_5 ha^{-1}, 180 kg K_2O ha^{-1}, and 15 kg boron ha^{-1}.

Experiment 2: The rapeseed cultivar, V3, was grown in the field from 2006 to 2007 on Yellow umber soil with higher fertility in pre-planting in soil in Nanjing (32° 03′N), Jiangsu Province. 2 treatments (direct seeding, and transplant), 3 replications, and 6 subplots arranged random with 3.00- by 2.50-m were set to the experiments. Fertilizing and other field managements in plots were the same.

Experiment 3: The rapeseed cultivars, V3 and V4, were grown in the field from 2007 to 2008 on Yellow umber soil with higher fertility in pre-planting in soil in Nanjing (32° 03′N), Jiangsu Province. The experiment included 2 cultivars and 2 nitrogen levels (Fertilizer: 0.018kg N m^{-2}; 0.012kg P_2O_5 m^{-2}; 0.018kg K_2O m^{-2}; and 0.0015kg borax m^{-2}; CK: no fertilizer), 4 treatments, 3 replications, and 12 subplots arranged random with 40.0-cm row spacing, 17-20 cm plant spacing in 7.00- by 4.30-m area. Fertilizing and other field managements in plots were the same.

The phenophase, LAI, the total shoot numbers, dry matter, leaf number, leaf photosynthesis, plant characters, and meteorological and soil data etc. were observed during rapeseed growth or after harvest.

3. CULTIVTION-SIMULATION-OPTIMIZATION DECISION MAKING SYSTEM FOR RAPESEED (Rape-CSODS)

3.1 Structure and Functions of Rape-CSODS

The system was developed based on the principles on eco-physiology for rapeseed, balance of soil nutrition and moisture, agricultural system science and agricultural meteorology, the optimization of rapeseed cultivation, and so on, and included rapeseed growth and optimization models, databases, system platform, and function (Fig.1). In that there were the simulation models for growth and development in rapeseed (see APPENDIX below), the optimization models of rapeseed cultivation (see APPENDIX below), and generating models for weather data (see APPENDIX below), there were mainly the parameters for weather, soil, and cultivars, and expert knowledge for managements for nutrition and water in soil and controlling for diseases, insect pests, and weeds in rapeseed in databases, there were the interface for decision making, databases, 4 sub-systems with parameter adjusting, decision making in normal year, decision making in current year, and analyzing for cultivar suitability in the system platform, and there were mainly determining the model parameter, the optimization cases and for rapeseed cultivation in normal year, the revising scheme for rapeseed cultivation in current year, suggestion for suitable plant areas for rapeseed cultivars, printing sheet for decision making, and so on.

The interface for decision making was developed using Visual Basic ver.6.0, which included main menu and first level sub-menu with linking every sub-systems (Fig.2 to Fig.5) with independent main interfaces and main menu, the background databases were designed using VFP ver. 6.0, and the output of the decision making results can link with Excel.1998-2007.

Fig. 2. The system main interface

Fig. 3. Browse of meteorological data in local

Fig. 4. Selection and input for cultivars

Fig. 5. The optimum fertilizer balance-sheet in the normal year

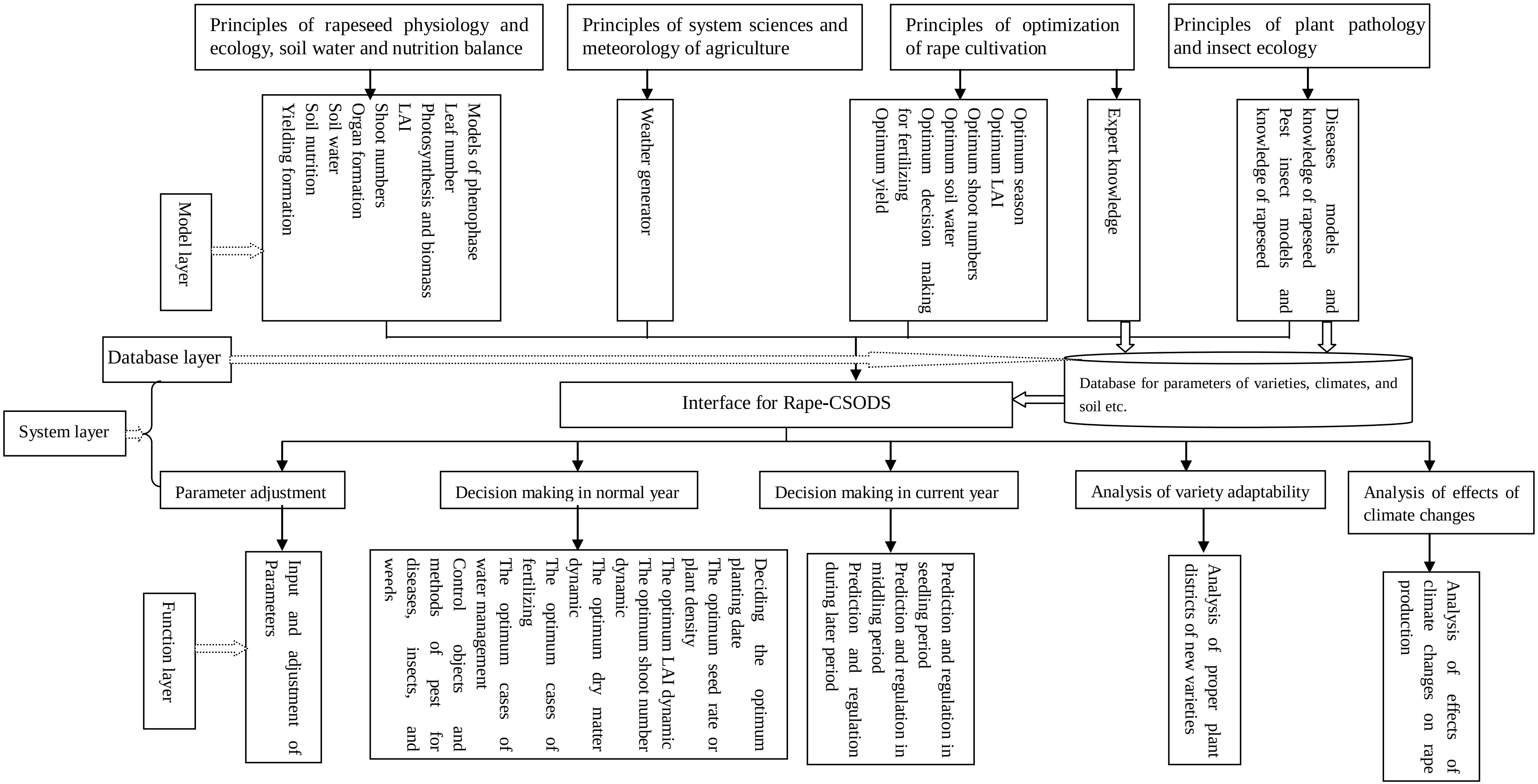

Fig. 1. Chart of the structure and functions of Rape-CSODS

3.2 Running Environment of System

3.2.1 Hardware

The system required personal computer with the model Pentium IV or above, disk driver, and laser or stylus printer.

3.2.2 Software

The system required WIN98 or above operation system, Visual Basic ver. 6.0, VFP ver. 6.0 or above, and Excel.1997 or above.

4. APPLICATION OF SYSTEM

4.1 Basic Situations of Site

Rape-CSODS was applied in Liaocheng of Shandong province in 2006-2007, and the demonstration area was at 7.73 ha located in Houlou Village, Jiazhai, Chiping County with planting pattern of direct seeding between rows of pre-crop corn.

The optimization scheme in normal year were gained by Rape-CSODS using the meteorological data in normal year in Liaocheng (Table 1), the average soil nutrition data in the demonstration area (soil texture, sandy loam; soil organic matter, 9.5 g kg^{-1}; total nitrogen, 0.83 g kg^{-1}; P_2O_5, 18.5 mg kg^{-1}; K_2O, 102 mg kg^{-1}), and the cultivar, "Qinyou 2" through combining the scheme with the local expert knowledge on Rapeseed. The managements of the demonstration area were carried in accordance with the optimization scheme from Rape-CSODS, and the control rapeseed field was used in the conventional managements under the same conditions such as soil, weather, and cultivar.

Table 1 Meteorological data in the normal year in Liaocheng

Months	Monthly mean temperature (℃)	Monthly mean maximum temperature (℃)	Monthly mean minimum temperature (℃)	Monthly sun time (h)	Monthly rainfall (mm)	Monthly rainy days (D)
1	-2.0	3.4	-6.6	162.0	4.3	2.5
2	0.9	6.1	-4.2	161.0	7.1	2.8
3	7.1	13.1	1.6	198.0	14.6	4.3
4	14.6	20.5	8.5	231.0	23.8	5.7
5	20.0	26.7	14.4	263.0	45.8	5.4
6	25.2	31.7	19.5	246.0	69.3	7.8
7	26.7	31.4	22.5	204.0	185.5	12.7
8	25.4	30.3	21.5	216.0	123.3	10.5
9	20.6	26.2	15.7	214.0	55.2	6.8
10	14.4	20.6	9.5	200.0	36.7	5.1
11	6.6	12.4	2.0	170.0	13.4	5.2
12	0.2	5.2	-4.2	157.0	6.1	2.4

4.2 Comparison of results

4.2.1 The Seedling situations in rapeseed before over-winter

The various indices of seedling status in rapeseed before over-winter in demonstration area were larger than that of the control, e.g. the green leaf numbers per plant, leaf area per plant, and dry matter per plant increased 1.1, 221 cm^2, and 1.5g, respectively (Table 2).

Table 2 Seedling status in rapeseed before over-winter in 2006

Items	Green leaf numbers per plant	Diameter of rootstalk (cm)	Leaf area per plant (cm2)	LAI	Fresh weight per plant (g)	Dry weight per plant (g)
Demonstration area(D)	10.6	1.4	1961	1.82	162.3	15.8
Control area(CK)	9.5	1.3	1740	1.73	151.4	14.3
±(D-CK)	1.1	0.1	221	0.09	10.9	1.5

The investigation date was on Dec. 20, 2006

4.2.2 The yield and yield components

Under the same conditions, 1000-grain weight and yield in demonstration area was larger than that of the control, e.g. the 1000-grain weight increased 0.2g, and the yield raised 676.5kg ha^{-1}, respectively (Table 3).

Table 3 Analysis on rapeseed yield and yield components in 2006-2007

Items	Plants (10^4/ ha)	Plant height (cm)	Length of available ramification (cm)	available ramification numbers on main stem	Length of main anthotaxy (cm)	Pod number on main anthotaxy	Pod number per plant	Seed number per pod	1000-weight (g)	Yields (kg/ ha
Demonstration area (D)	17.1	1.65	38.4	8.3	55.5	76	336.2	18.1	3.4	2829.0
Control area (CK)	17.1	1.55	35.1	6.9	49.3	71	258.5	17.9	3.2	2152.5
±(D-CK)	0	0.10	3.3	1.4	6.2	5	77.7	0.2	0.2	676.5

5. DISCUSSION AND CONCLUSIONS

5.1 Disscussion

At present, the development direction of rapeseed production is the high yield, good quality and end-uses, therefore, it is a basic guarantee of health development of rapeseed production to realize regionalization of distribution, large regional precision planting, standardization of production, and informationalization of managements.

Regionalization of distribution

Analysis of cultivar adaptability can be made by Rape-CSODS, which will help to know possible proper plant regions of cultivars, and develop potential extensive values for it. Of course, in order to fulfill this purpose, it is need to integrate with GIS.

Large scale precision planting

In the large scale planting, it is need to decide corresponding plant sheets under different weather, soil, and cultivar conditions, and the purposes can be realize using Rape-CSODS quickly expediently easily. In addition, the decision making with precision and digital can be done by Rape-CSODS, which will also help to realize precision planting, and it is a precision planting technology with low-cost.

Standardization of production

The cultivation practices with standardization can be integrated in pre-sowing plant sheet, which is a benefit references for planter. As long as you done according to it, standardization of production can be fulfilled.

Informationalization of managements

Informationalization of crop managements is one of crucial contents for modern agriculture. The Rape-CRSODS and its application in rapeseed production set a basis for informationalization management of rapeseed production. With wide use of internet, informationalization management can be more feasible in agriculture, therefore, it is need to be integrated with internet.

5.2 Conclusions

Rape-CSODS contained simulation models for growth and development in rapeseed, the optimization models of rapeseed cultivation, and expert knowledge databases for managements for nutrition and water in soil and controlling for diseases, insect pests, and weeds in rapeseed, in that the rapeseed growth models mainly included phenophase, leaf age, population dynamic, and organ forming etc., and the optimization models for rapeseed cultivation mainly included the optimum biomass, the optimum LAI, the optimum shoot and ramification number dynamics models, and the optimum decision making models for nitrogen and water etc. The Rape-CSODS was a system with general adaptability, clear yield aim, better mechanism, and dynamic characteristic.

The system has been applied in Shandong Province in this study, and the results showed that the scheme get by Rape-CSODS can increase green leaf number before over-winter, 1.1; 1000-weight, 0.2g; and rapeseed yield, 676.5kg ha^{-1} at mature, comparing with the control in the same conditions.

The Rape-CSODS was a result of applying crop simulation technology in rapeseed cultivation, managements, and informational management system for rapeseed cultivation, which overcome lag and non-dynamic disadvantages of results from 2-3 year field experiment data on cultivation conventionally, and had a huge market and wide application foreground.

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APPENDIX

Simulation models for growth and development in rapeseed

Phenology

The basic models of rapeseed phenology were developed in the thesis through employing ideal of

"Rice Clock Models" (Gao *et al*., 1992; Cao *et al*., 2005, 2006, 2009, 2010).

$$dP_j/dt = 1/D_{Sj} = e^{kj} (T_{ebj})^{pj} \cdot (T_{euj})^{qj} \cdot (P_{ej})^{Gj} \cdot f(E_{Ci})$$

$$T_{ebj} = (T_i - T_{bj}) / (T_{oj} - T_{bj}), \text{ when } T_i<T_{bj}, T_i= T_{bj}; \text{ when } T_i>T_{oj}, T_i =T_{oj}$$

$$T_{euj} = (T_{uj} - T_i) / (T_{uj} - T_{oj}), \text{ when } T_i >T_{uj}, T_i= T_{uj}$$

$$P_{ej} = (P_i - P_{bj}) / (P_{oj} - P_{bj}), \text{ when } P_i<P_{bj}, P_i= P_{bj}; \text{ when } P_i>P_{oj}, P_i =P_{oj}$$

where dP_j/dt is the development rate at the j^{th} stages, D_{Sj} is the days at the j^{th} stages, T_{ebj} and T_{euj} are the effective factors for temperature, respectively, pj and qj are the genotypic coefficient of temperature effects, P_{ej} is the effective factor of photoperiod, Gj is the genotypic coefficient of photoperiod effects, and $f(E_{Ci})$ is the effective function of agronomic practice factors for rapeseed, T_i is the daily mean temperature (℃) in the j^{th} stage, T_{bj}、T_{oj} and T_{uj} are lower, optimum, and upper limit temperature (℃) demanded in the j^{th} stage for rapeseed, respectively, and P_{bj}、P_{oj} are the critical and optimum day length (h) demanded in j^{th} stage for rapeseed, respectively.

Vernalization models can be described as following through employing ideals of "wheat clock models":

$$dV/dt = 1 / D_{s2} = e^{k2} (V_e)^C$$

If a cultivar was winter or semi-winter rapeseed, the expression of V_e was:

$$V_e = \begin{cases} \frac{V_{ti}+4}{9}, & -4 < V_{ti} \le 5℃ \\ 1.0, & 5<V_{ti} \le 10℃ \\ \frac{20-V_{ti}}{10}, & 10<V_{ti} \le 20℃ \\ 0, & V_{ti} \le -4 ℃ \text{ or } V_{ti} > 20℃ \end{cases}$$

However, if it was spring rapeseed, the expression of V_e was:

$$V_e = \begin{cases} \frac{V_{ti}}{5}, & 0 < V_{ti} \le 5℃ \\ 1.0, & 5<V_{ti} \le 20℃ \\ \frac{30-V_{ti}}{10}, & 20<V_{ti} \le 30℃ \\ 0, & V_{ti} \le 0 ℃ \text{ or } V_{ti} > 30℃ \end{cases}$$

where K2 and C are the parameters of vernalization, V_e is the factor of rapeseed vernalization effect, V_{ti} is the daily mean temperature in vernalization phase. It will finish vernalization phase when V_e equal to some extent accumulation days; the vernalization days of the winter rapeseed were 30 to 40 days, the semi-winter rapeseed with 20 to 30 days, and the spring rapeseed with 15 to 20 days.

Leaf age

The growth rate of rapeseed leaf were different in different varieties, development stages, temperature, and nutrition conditions etc., when nutrition condition was optimum, the models of rapeseed leaf age were (Gao *et al*., 1992; Cao *et al*., 2005, 2006, 2009, 2010):

$$dL_j/dt = f(L_j) = 1/D_{Lj} = D_{Loj} (T_t/T_o)^{La/Lb}$$

$$T_t = \begin{cases} 0, & \text{when } T_t < T_{bj} \\ T_o, & \text{when } T_t > T_o \end{cases}$$

$$D_{Loj} = e^{LK}$$

where dL_j/dt is the development rate of the j^{th} leaf age, $f(L_j)$ is the basic development function, D_{Lj} is the development days demanded from emergence to the j^{th} leaf age, D_{Loj} is the development days demanded from emergence to the j^{th} leaf age under the optimum conditions, T_t and T_o are the daily mean temperature(℃) of the t^{th} day, and the optimum temperature for rapeseed leaf age development, respectively, and La、Lb、LK are the parameters of leaf models, respectively.

Dry matter

It was results of accumulation and partitioning in various rapeseed organ of assimilate of photosynthesis, the accumulation of dry matter in whole rapeseed growth season was a process with “S-curve” changes. Therefore, simulation models of rapeseed dry matter dynamic were (Gao *et al*., 1992; Cao *et al*., 2005, 2006, 2009, 2010):

$$W(t)= W(t-1) +\triangle W(t)$$

$$\triangle W(t) = \begin{cases} \beta \cdot P_{CG} - R, & \text{before elongation} \\ \dfrac{\beta \cdot P_{CG} - R}{1-0.2}, & \text{after elongation to early anthesis} \\ \dfrac{\beta \cdot P_{CG} - R}{1-0.2-0.4}, & \text{after early anthesis} \end{cases}$$

where W(t) and W(t-1) are the dry matter (g) of population in the t^{th}, and the $(t-1)^{th}$ day after emergence, respectively, $\triangle W(t)$ is the net increment (g) of dry matter of population in the t^{th} day after emergence, P_{CG} is the canopy photosynthesis rate of rapeseed (g co_2 m^2 h^{-1}), R is the respiration rate (g co_2 m^2 h^{-1}), β is the coefficient transforming carbohydrate into dry matter in rapeseed, 0.2 and 0.4 are ratio of photosynthesis of green stem and pod in whole photosynthesis in the same periods.

LAI

In terms of principles of dry matter partitioning for rapeseed, the simulation models of LAI before early anthesis were (Gao *et al*., 1992; Cao *et al*., 2005, 2006, 2009, 2010) :

$$L_{AI}(t)=L_{AI}(t-1)+\Delta L_{AI}(t)$$

$$\Delta L_{AI}(t)= L_{AII}(t)- L_{AID}(t)$$

$$L_{AII}(t)=C_P(t) \cdot \Delta W(t) \cdot R_{LA}(t)$$

where $L_{AI}(t)$ and $L_{AI}(t-1)$ are LAI in the t^{th}, and the $(t-1)^{th}$ day after emergence, respectively, $\Delta L_{AI}(t)$ is the daily net increment of LAI in the t^{th} day after emergence, $L_{AII}(t)$ and $L_{AID}(t)$ are the total daily increment and decrement in the t^{th} day after emergence, respectively, $C_P(t)$, $\Delta W(t)$, and $R_{LA}(t)$ were partitioning coefficient of dry matter in leaf, daily accumulation rate of dry matter in plant (g · m^{-2} · d^{-1}), and ratio of leaf area to dry matter (m^2 · g^{-1}), respectively.

It’s decreasing after early anthesis was a function of development index:

$$L_{AI}(t)=\frac{L_{AIX}}{1+d1\times D_{VI}(t)^2}$$

$$D_{VI}(t)=\sum_{i=1}^{t} DPDi/No$$

where L_{AIX} is the largest LAI of rapeseed in whole growth period, $D_{VI}(t)$ is the development index in t^{th} day after anthesis with ranges between 0 and 1, No is development physiological days from early anthesis to mature, and d1 is a parameter of models.

Total shoot and ramification numbers

The increasing models of shoot and ramification numbers from elongation to early anthesis were (Gao *et al*., 1992; Cao *et al*., 2005, 2009, 2010):

$$T_{ILN}(t) = T_{ILN}(t-1) + \Delta T_{ILN}(t)$$

$$\Delta T_{ILN}(t) = K_{TLNI}(t)\, T_{ILN}(t-1)\, D_{PD}(t)\, P_{TILN}(t)$$

$$P_{TILN}(t) = 1- T_{ILN}(t-1) / T_{ILNM}$$

$$K_{TLNI}(t) = K_{TLNO} \cdot T_{LNF}(t)$$

The decreasing models of shoot and ramification numbers from early anthesis to mature were:

$$T_{ILN}(t) = T_{ILN}(t-1) - \Delta T_{ILN}(t)$$
$$\Delta T_{ILN}(t) = K_{TLNI}(t) \cdot T_{ILN}(t-1) \cdot D_{PD}(t) \cdot P_{TILN}(t)$$
$$P_{TILN}(t) = 1 - T_{ILN}(t-1) / T_{ILNM}$$
$$K_{TLNI}(t) = K_{TLNO} \cdot T_{LNF}(t)$$

where $T_{LNF}(t)$ is the effective factor of the total leaf numbers in the t^{th} day after emergence, $T_{ILN}(t)$ and $\Delta T_{ILN}(t)$ are the total shoot and ramification numbers, and its daily increment (number m^{-2}) in the t^{th} day after emergence, respectively, $T_{ILN}(t-1)$ is an initial value of the total shoot and ramification numbers in the $(t-1)^{th}$ day after emergence(number m^{-2}), T_{ILNM} is the largest numbers of total shoot numbers (number m^{-2}), $P_{TILN}(t)$ is the ratio of total shoot and ramification numbers in the t^{th} day after emergence to T_{ILNM}, $D_{PD}(t)$ was the development physiological days in the t^{th} day after emergence, and $K_{TLNI}(t)$ is increasing coefficient of shoot and ramification numbers in the t^{th} day after emergence, which was decided by nitrogen, light, temperature, and soil moisture etc.

Optimization models in rapeseed

Optimum season

There was an overyear in growth and development of winter rapeseed, so an important basis of deciding the optimum planting date was to get the happy seedling under diffrent varieties and cropping systems. The green leaf numbers per plant pre-overyear can be as the happy seedling criteria based on studies of Institute of Oil Crops Research, CAAS. At first, the optimum planting date was calculated by leaf age models above, then, the other optimum phenology were calculated by phenophase models above (Gao *et al*., 1992; Cao *et al*., 2005, 2009, 2010).

Optimum leaf age

The models of optimum leaf age of rapeseed were expressed as below under the optimum nutrition conditions, and the leaf development affected only by temperature (Gao *et al*., 1992; Cao *et al*., 2005, 2009, 2010):

$$dL_{oj}/dt = f(L_{oj})$$
$$f(L_{oj}) = 1/D_{Loj} = D_{Loj}\ (T_t/T_o)^{a/b}$$

where dL_{oj}/dt is the development rate in the j^{th} leaf age, $f(L_{oj})$ is a basic development function of leaf age, D_{Lj} is the development days demanded from emergence to the j^{th} leaf age, D_{Loj} is the development days demanded from emergence to the j^{th} leaf age under the optimum conditions, and T_t and T_o are daily mean temperature in the t^{th} day, and the optimum temperature for development of leaf age (℃), respectively.

Optimum LAI

The optimum LAI in different phenophase (L_{AIO}) of rapeseed can be expressed as follows (Gao *et al*., 1992; Cao *et al*., 2005, 2009, 2010):

$$L_{AIO} = -(1/E_j)\ \ln(B\ I_b / I_0)$$

where I_0 is the horizontal nature light intensity above the population in the j^{th} phenology in the local, which equals to product of daily mean solar radiation by coefficient (C), $(B\ I_b)$ is the light intensity of lower part of population in the j^{th} phenology, E_j is the extinction coefficient of population in the j^{th} phenology, I_b is the compensating light intensity of lower part of population in the j^{th} phenophase.

Optimum dry matter

The optimum dry matter at different phenology and yielding levels equals to dry matter in the optimum LAI pre-elongation, that in the optimum LAI, and green stem area from elongation to pre-anthesis, and that in the optimum LAI, green stem area, and PAI, and its basic models can be expressed as follows (Gao *et al.*, 1992; Cao *et al.*, 2005, 2009, 2010):

$$W_o(t) = W_o(t-1) + \triangle W_o(t)$$

$$\triangle W_o(t) = \begin{cases} \beta \cdot P_{CGO} - R_O, & \text{before elongation} \\ \dfrac{\beta \cdot P_{CGO} - R_O}{1 - 0.2}, & \text{after elongation to early anthesis} \\ \dfrac{\beta \cdot P_{CGO} - R_O}{1 - 0.2 - 0.4}, & \text{after early anthesis} \end{cases}$$

where $W_o(t)$ and $W_o(t-1)$ are the optimum dry matter of rapeseed population in the t^{th} day, and $(t-1)^{th}$ day after emergence (g), respectively, $\triangle W_o(t)$ is the net increment of the optimum dry matter of rapeseed population in the t^{th} day after emergence (g), P_{CGO} is the optimum canopy photosynthesis rate (g co_2 m^2 h^{-1}), 0.2 and 0.4 are ratio of photosynthesis of green stem and pod in whole photosynthesis in the same periods, and the other signs are the same above.

Optimum shoot and ramification numbers

The models of the optimum shoot and ramification numbers of rapeseed population (N_{FO}) ($10^4 \times ha^{-1}$) can be expressed as follows (Gao *et al.*, 1992; Cao *et al.*, 2005, 2009, 2010):

$$B_{SO} = N_{MF} / N_{SV}$$

$$N_{SV} = L_N / 4 + k \quad + 1$$

$$N_{FO} = N_{MF} + N_S B_{SO}$$

$$N_S = \begin{cases} 0, & N_F \leq 8 \text{ or } N_F > 16 \\ 9, & 9 \leq N_F \leq 10 \\ 12, & 11 \leq N_F \leq 12 \\ 20, & 13 \leq N_F \leq 16 \end{cases}$$

where B_{SO} is the optimum plant numbers ($10^4 \times ha^{-1}$), N_{MF} is the optimum main stem and primary shoot numbers ($10^4 \times ha^{-1}$), relying on yielding levels, N_{SV} is the valid shoot and ramification numbers per pant, and N_F and N_S are the optimum primary, and secondary ramification numbers per plant, respectively.

Optimum decision making of ecological and balance sheet for fertilizing

Based on the principles for balance sheet for fertilizing, the nutrition of fertilizer in rapeseed can be calculated as follows (Gao *et al.*, 1992; Cao *et al.*, 2005, 2009, 2010):

$$F_{NQ} = (F_{AQ} - F_{SQ})/E_F$$

where F_{AQ} is the nutrition rate demanded in whole rapeseed growth, F_{SQ} is the nutrition rate supplied by soil, the effects of the ecological factors such as the soil nutrition contents, soil organic matter, pH, and soil temperature etc on F_{SQ} can be considered, and E_F is the use efficiency of fertilizer in the rapeseed growth season.

Optimum decision making of soil moisture

Based on the principles for soil moisture balance, the models of profit and loss of soil water in rapeseed growth season can be expressed as follows (Gao *et al.*, 1992; Cao *et al.*, 2005, 2009, 2010):

$$D_{SW}(t) = I_{SW}(t) - O_{SW}(t)$$

$$O_{SW}(t) = E_{TA}(t) + R_U(t) + C(t)$$

$$I_{SW}(t) = W_0(t) + P(t)$$

where $D_{SW}(t)$ is profit and loss of soil water in the t^{th} day (mm), $I_{SW}(t)$ and $O_{SW}(t)$ are capture, and loss of soil water in the t^{th} day (mm) in current or normal year, respectively, $E_{TA}(t)$、$R_U(t)$ and $C(t)$ are actual evaporation-transpiration, runoff, and intercept in the t^{th} day(mm), respectively, $W_0(t)$ is initial soil moisture in the t^{th} day (mm), and $P(t)$ is rainfall in the t^{th} day(mm).

Generating models for weather data

According to Gao *et al*. (1992a), the daily day length, DL_j, and daily radiation, QD_j, can be calculated below.

$$SL = 23.5 \times \sin (6.2832 \times (284 + j) / 365)$$

$$D6 = \sin ((45 - (LT - SL - 0.565) / 2) \times 3.1416 / 180)$$

$$D7 = \sin ((45 + (LT - SL + 0.565) / 2) \times 3.1416 / 180)$$

$$D8 = \cos (LT \times 3.1416 / 180) \times \cos (SL \times 3.1416 / 180)$$

$$D10 = (2\tan^{-1}(\frac{\sqrt{(D6 \times D7)/D8}}{\sqrt{(1-(D6 \times D7)/D8)}})) \times \frac{180}{\pi}$$

$$DL_j = (D10/15) \times 2$$

$$C1 = 3.1416 / (1 + (3.191 \times \cos (\omega \times j) + 0.695 \times \sin(\omega \times j)) / 100)$$

$$C2 = \sin (LT \times 3.1416 / 180) \times \sin (SL \times 3.1416 / 180) \times D10 \times (3.1416 / 180)$$

$$C3 = D8 \times \sin (D10 \times 3.1416 / 180)$$

$$QAX = (1.94 \times 1440) / C1 \times (C2 + C3)$$

$$QD_j = QAX \times (0.146 + 0.559 \times (ST[j]/10) / DL_j)/23.8846$$

where SL is solar latitude, j is day number, LT is local latitude, ω is solar constant (taking $\omega = 6.28 / 365$), and ST[j] is sun time on j^{th} day.