Using Multi-Dimension Dynamic Planning Based on RAGA to Optimize Irrigation System under Non-Sufficient Irrigation Condition

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Abstract: By utilizing the real coding based accelerating genetic algorithm (RAGA) and multi-dimension DP, a method named RAGA—DP was developed to optimize irrigation system of well irrigated rice under non-sufficient irrigation condition in the Sanjiang Plain. When using DP to optimize irrigation system under non-sufficient irrigation condition, the model works well for problems such as difficulty to identify the optimal value. The results of model were analyzed and found in a good agreement with the actual conditions. [The Journal of American Science. 2005;1(1):68-74].

Key Words: well-irrigated rice; optimization; irrigation system; RAGA; DP

1. Introduction

In general, the water consumption for growing rice can take up to 80 and 90 percent of the whole agricultural water resource. At present, the scarce of water resource is a serious problem worldwide. Therefore, it is very important to study the problem of optimum rice irrigation system under the non-sufficient irrigation conditions. The objective of designing the optimum irrigation system under non-sufficient irrigation is to reasonably distribute the certain water resource to every growth phases. The traditional method to deal with the issue adopts the method of dynamic programming approach (DPSA). That is to divide a two-dimension dynamic programming into two one-dimension dynamic programming. But the method of DPSA can not ensure to get the best result in any complexion. Therefore, we proposed a new method named RAGA-DP to deal with this kind of issue. RAGA means the real coding based on accelerating genetic algorithm. With combining RAGA and DP, several parameters can be optimized at one time. Furthermore, RAGA can calculate the best result in the whole scope and avoid to convergent advanced. In the article, a case study has been discussed to introduce the application of RAGA-DP model (Cui, 2000; Li, 1999).

2. Real Coding Based Accelerating Genetic Algorithm (RAGA)

2.1 Brief Introduction of GA

Genetic Algorithm has been developed by Professor Holland in USA. The main operation includes selection, crossover and mutation (Jin, 2000; Zhou, 2000).

2.2 Real Coding Based Accelerating Genetic Algorithm (RAGA)

The coding mode of traditional GA adopted binary system. But binary system coding mode has many shortcomings. Therefore, based on the work of Jin and Ding (2000), we proposed a new method named RAGA (Real coding based Accelerating Genetic Algorithm). RAGA includes 8 steps as follows. For example, to calculate the following optimization problem:

Max: f(X)

s.t. $: a_j \le x_j \le b_j$

Step 1: In the scope of $\lfloor a_j, b_j \rfloor$, random variable of N group uniformity distribution can be created $V_i^{(0)}(x_1, x_2, \cdots x_j, \cdots x_p)$. $i = 1 \sim N$, $j = 1 \sim p$. N——the group scale. p —— the number of optimal parameter.

Step 2: To calculate the objectives: Putting the original series so called "chromosome" $V_i^{(0)}$ into objective function, the corresponding function $f^{(0)}(V_i^{(0)})$ can be calculated. According to the function, the chromosome dispose from big to small has been made and then, obtained $V_i^{(1)}$.

Step 3: Calculate the evaluation function based on order expresses as $eval(V)$. The evaluation function gives a probability for each chromosome V. It makes the probability of the chromosome to be selected fits for the adaptability of other chromosomes. The better the adaptability of chromosome is that it is much easier to be selected. Thus, if parameters $\alpha \in (0,1)$, then the evaluation function based order can be expressed as follows:

$$eval(V_i) = \alpha(1-\alpha)^{i-1}, \quad i = 1,2,\cdots,N$$

Step 4: Selecting operation. The course of selecting is based on circumrotating the bet wheel N times. We can select a new chromosome from each rotation. The bet wheel selects the chromosome according to the adaptability. After selecting, a new group $V_i^{(2)}$ should be obtained.

Step 5: Crossover operation. Firstly, we define the parameter P_c as the crossover probability. In order to ensure the parent generation group to crossover, we can repeat the process from $i = 1$ to N as follows. Create random number r from [0，1]. If $r < P_c$, V_i may be taken as parent generation and $V_1', V_2', \cdots$ may be selected for male parent. Meanwhile, the chromosome may be divided into random pair based on arithmetic crossing method, as following.

$$X = c \cdot V_1' + (1-c) \cdot V_2' \qquad Y = (1-c) \cdot V_1' + c \cdot V_2'$$

c ——a random number from (0,1).

We can obtain a new group $V_i^{(3)}$ after crossover.

Step 6: Mutation operation. Define the P_m as the mutation probability. The mutation direction d is randomly selected from R^n. If $V + Md$ is not feasible, a random number M can be taken from 0 to M' until the value of $V + Md$ is feasible. M is an enough big number. Then, V can be replaced with $X = V + Md$. After mutation operation, a new group $V_i^{(4)}$ can be obtained.

Step 7: Evolution iteration. From step 4 to step 6, the final generation $V_i^{(4)}$ can be obtained and disposed according to adaptability function value from big to small. Then, the arithmetic comes into the next evolution process. Thus, the above steps have been operated repeatedly until the end.

Step 8: The above seven steps make up of Standard Genetic Arithmetic (SGA), but SGA can not assure the whole astringency. The research indicates that the crossover seeking optimal function has worn off along with the iteration times increases. In practical application, SGA will stop working when it is far away from the best value. Many studies have confirmed or repeated this. Based on reference (Jin, et al, 2000), the interval of excellence individual during the course of the first and the second iteration has been adopted as the new interval. Then, the arithmetic comes into step 1, and runs SGA over again to form acceleration running. Thus, the interval of excellence individual will gradually reduce, and the distance is closer to the best value. The arithmetic will not stop until the function value of best individual less than a certain value or exceed the destined accelerate times. At this time, the currently group will be destined for the result of RAGA.

The above 8 steps make up of RAGA.

3. Inquire Into the Rice Optimum Irrigation System Under Non-sufficient Irrigation Based on Two-dimension Dynamic Programming

The method of building the DP model is as follows.

Step 1: Define the model of rice water production function. According to the practical data of the area of Sanjiang Plain in 1998 (normal year) and 1999 (medium drought year) the sensitive exponent can be calculated by using model of Jensen. The form of Jensen model is as follows.

$$\frac{Y_a}{Y_m} = \left(\frac{ET_{(1)}}{ET_{m(1)}}\right)^{0.1563} \cdot \left(\frac{ET_{(2)}}{ET_{m(2)}}\right)^{0.2892} \cdot \left(\frac{ET_{(3)}}{ET_{m(3)}}\right)^{0.5283} \cdot \left(\frac{ET_{(4)}}{ET_{m(4)}}\right)^{0.1240} \quad (1999)$$

Step 2: Define the available rainfall and seepage quantity. The rice irrigation system is related to the rainfall and distribution in time and space during the whole growth period. At the same time, the seepage quantity in the field will influence the rice water consumption and irrigation system (Li, 1999; Kang, 1996; Guo, 1994; Zhu, 1998).

(1) Define the available rainfall.

The maximum allowable water depth is limited to 20 mm. The rainfall should be drained if it exceeds 20 mm. The process is as the following (Li, 1999).

$$P_0 = \begin{cases} P, & P \le H_{max} - H_{min} \\ H_{max} - H_0, & P > H_{max} - H_0 \end{cases}$$

P_0 ——The available rainfall of once rainfall (mm); P ——The rainfall of once rainfall (mm).

H_0 ——The water depth in the field at the beginning of the rainfall (mm).

H_{max} ——The maximum sluiced allowed depth in the field (mm).

(2) Seepage quantity in the paddyfield (Li, 1999; Guo, 1994).

The days (d_i) in phase i are calculated based on the following formula:

$$d_i = \frac{h_i + m_i + P_i}{\overline{ET}_i + \overline{K}_i}.$$

In formula: $\overline{ET}_i$ 、 $\overline{K}_i$ —— the daily mean evapotranspiration and seepage quantity under the condition of supplying water normally (mm).

h_i ——the water depth in the field of phase i (mm).

m_i ——irrigation quantity of phase i (mm).

P_i ——the available rainfall of phase i (mm).

If D_i is as the total days of phase i , then $d_i < D_i$. Let $D_i - d_i$ as the days without water depth in phase i , then the seepage quantity of paddy field in phase i can be expressed as following:

$$K_i = \overline{K}_i \cdot d_i + \sum_{j=1}^{D_i - d_i} \left(\frac{1000 \cdot K_0}{1 + K_0 \cdot \alpha \cdot t_j / H} \right).$$

K_0 —— saturation waterpower conductivity (m/d). It is relative to the quality of soil. The common value is 0.1～1.0.

α ——experience constant. The common value is 50～250.

t_j ——the days of soil water-content coefficient from saturated states to the j th day.

H ——the depth of rice main root-layer (m).

Step 3: Define the mathematical model (Li. 1999; Guo, 1994).

(1) Phase variables.

According to the rice growth process, the whole growth period can be divided into N parts in different days. The phase variables are $n = 1,2,\cdots,N$.

(2) Decision-making variables.

There are two decision-making variables to be defined: One is practical duty m_i , the other one is practical evapotranspiration $(ET_a)_i$ ($i = 1,2,\cdots,N$). The evapotranspiration is the function of soil moisture, crop and weather factors. Because the function is rather complex it is very difficult to define. Treating it as the decision-making variable is an approximate method.

(3) State variables.

There are two state variables to be defined. One is the water quantity that can be distributed at the beginning of each phase, (q_i). The other one is the sluiced water depth in the field at the beginning of each phase. When the paddyfield is non-saturation State, h_i will be the function of soil water-content coefficient. If the depth of saturation state equals zero, the depth h_i will be negative at this time as the following formula: $h_i = 10\gamma H(\theta - \theta_s)$.

H ——the depth of planned wet layer (mm).

θ_s ——soil saturation water-content coefficient.

θ ——the soil average water-content coefficient of planned wet layer.

γ ——soil dry density (t/m^3).

(4) System equation.

System equation can describe the transferred state in movement. Because there are two state variables, there are two system equations too.

The first one is water distribution function. If decision-making m_i of growth phase i can be adopted the following equation will be carried out: $q_{i+1} = q_i - m_i$.

q_i, q_{i+1} —— the allowed distributed water quantity in phase i and phase $i+1$ (mm).

m_i ——the duty of phase i (mm).

The second one is water balance equation: $h_{i+1} = h_i + P_i + m_i - (ET_a)_i - C_i - K_i$.

h_i, h_{i+1} ——the water depth in the field at the beginning of phase i and $i+1$ (mm).

C_i ——tonnage in phase i .

(5) Objective function.

Jensen model is adopted. The objective function is to get the maximum ratio of practical yield Y_a and the tiptop yield Y_m in unit area:

$$F = max\left(\frac{Y_a}{Y_m}\right) = max \prod_{i=1}^{N} \left(\frac{ET_a}{ET_m}\right)_i^{\lambda_i}.$$

(6) Restricted conditions.

① Decision-making restriction.

$$0 \le m_i \le q_i, \quad \mathrm{i} = 1,2,\cdots,\mathrm{N}, \quad \sum_{i=1}^{N} m_i = Q$$

$$(ET_{min})_i \le (ET_a)_i \le (ET_m)_i \quad \mathrm{i} = 1,2,\cdots,\mathrm{N}.$$

Q ——the allowed distributed water quantity in unit area during the whole growth period (mm).

$(ET_m)_i$ 、 $(ET_{min})_i$ —— the maximum and minimum evapotranspiration of phase i (mm).

② the water depth in the field h_i : $(H_{min})_i \le h_i \le (H_{max})_i$.

$(H_{max})_i$, $(H_{min})_i$ ——the upper and lower limit of water depth in the field of phase i (mm).

The value of $(H_{max})_i$ can be defined by practical irrigation experience. The value of $(H_{min})_i$ can be defined according to the saturation water-content coefficient. It can be adopted 80 percent of water-content coefficient. In general, the value of it is negative.

(7) The original condition.

① The original water depth in the field is: $h_1 = h_0$.

h_0——the water depth after transplanting rice seedlings. In general, h_0 equals $20\,mm$.

② The allowed distributed water quantity in the first phase equaling the supplied water quantity in the whole growth period is: $q_1 = Q$.

Step 4: Calculate the mathematical model.

When the parameters are optimized with applying RAGA, the best value of objective function can be found.

4. The Number of Every Phase (The Concrete Data See Also To Table 1)

The number of every phase is as follows:

①—return green and tilling phase. ②—joint and booting phase. ③ tassel and bloom phase. ④ prophase of mature (Table 1).

Table 1. The Original Data of Calculating the Optimum Irrigation System Under Non-Sufficient Irrigation in Fujin Area of Sanjiang Plain

Year	Items	Growth phase			
		①	②	③	④
1998	D_i (day)	42	10	7	20
	$(ET_m)_i$ (mm)	337.96	129.6	66.22	114.4
	P_i (mm)	87	96.5	39.5	42.6
	$\overline{K}_i$ (mm)	3.56	3.81	3.06	3.15
	$\overline{ET}_i$ (mm)	8.05	12.96	9.46	5.72
	λ_i	0.1785	0.3096	0.5509	0.1306
1999	D_i (day)	42	10	7	20
	$(ET_m)_i$ (mm)	347.55	126.4	71.89	150.8
	P_i (mm)	49	84.8	37.4	35.7
	$\overline{K}_i$ (mm)	3.33	3.70	3.10	3.30
	$\overline{ET}_i$ (mm)	8.28	12.64	10.27	7.54
	λ_i	0.1341	0.2687	0.5056	0.1174
	$(H_{max})_i$ (mm)	40	50	50	40
	$(H_{min})_i$ (mm)	-30	-50	-60	-65
$K_0 = 0.15 \quad \alpha = 200 \quad H = 0.4m$					

Take the data of 1999 as the example:

(1) Define the objective function:

$$F = max\left(\frac{Y_a}{Y_m}\right) = max\prod_{i=1}^{N}\left(\frac{ET_a}{ET_m}\right)_i^{\lambda_i} = \left(\frac{ET_{(1)}}{\mathrm{ET}_{\mathrm{m(1)}}}\right)^{0.1341}\cdot\left(\frac{ET_{(2)}}{\mathrm{ET}_{\mathrm{m(2)}}}\right)^{0.2687}\cdot\left(\frac{ET_{(3)}}{\mathrm{ET}_{\mathrm{m(3)}}}\right)^{0.5056}\cdot\left(\frac{ET_{(4)}}{\mathrm{ET}_{\mathrm{m(4)}}}\right)^{0.1174} \quad (1)$$

(2) Define the optimum parameters and restricted conditions.

Suppose: $q_1 = q_0 = Q$, $h_1 = h_0 = 20mm$

Q——the total supplied water quantity input by user (mm).

a_k —— the variable in the software MATLAB5.3. $k = 1,2,\cdots,M$, the M is the number of optimizing parameters.

$$\text{Let: } \begin{cases} q_2 = a_1 \\ q_3 = a_2 \\ q_4 = a_3 \end{cases} \quad (2) \qquad \begin{cases} m_1 = a_4 \\ m_2 = a_5 \\ m_3 = a_6 \\ m_4 = a_7 \end{cases} \quad (3)$$

$$\begin{cases}(ET_a)_1 = a_8 \\ (ET_a)_2 = a_9 \\ (ET_a)_3 = a_{10} \\ (ET_a)_4 = a_{11}\end{cases} \quad (4) \qquad \begin{cases}h_2 = a_{12} \\ h_3 = a_{13} \\ h_4 = a_{14} \\ h_5 = a_{15}\end{cases} \quad (5)$$

According to restricted equation, state equation and formula (2) to (5), the relation among the parameters can be set up:

$$\begin{cases}a_1 = Q - a_4 \\ a_2 = a_1 - a_5 \\ a_3 = a_2 - a_6\end{cases} (6) \begin{cases}a_8 = a_4 - a_{12} + h_1 + P_1 - K_1 \\ a_9 = a_{12} + a_5 - a_{13} + P_2 - K_2 \\ a_{10} = a_{13} + a_6 - a_{14} + P_3 - K_3 \\ a_{11} = a_{14} + a_7 - a_{15} + P_4 - K_4\end{cases} \quad (7)$$

The restricted conditions are formula (8) to (12).

$$\begin{cases}0 \le a_1 \le Q \\ 0 \le a_2 \le Q \\ 0 \le a_3 \le Q\end{cases} \quad (8) \qquad \begin{cases}-50 \le a_{12} \le 50 \\ -60 \le a_{13} \le 50 \\ -65 \le a_{14} \le 40 \\ -65 \le a_{15} \le 40\end{cases} \quad (9)$$

$$\begin{cases}0 \le a_4 \le Q \\ 0 \le a_5 \le a_1 \\ 0 \le a_6 \le a_2 \\ 0 \le a_7 \le a_3\end{cases} \quad (10) \qquad \begin{cases}0 \le a_8 \le 347.55 \\ 0 \le a_9 \le 126.4 \\ 0 \le a_{10} \le 71.89 \\ 0 \le a_{11} \le 150.8\end{cases} \quad (11)$$

$$a_4 + a_5 + a_6 + a_7 = Q \quad (12)$$

From the above equation, 15 parameters at the same time should be optimized.

(2) Define the originally varied region of each optimum parameter (See also to Table 2).

Table 2. The Originally Varied Region of Each Parameter Based on RAGA

Parameter	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}
Lower limit	0	0	0	0	0	0	0	0	0	0	0	-50	-60	-65	-65
Upper limit	Q	Q	Q	Q	Q	Q	Q	347.55	126.4	71.89	150.8	50	50	40	40

(3) Seek the best value based on RAGA.

During the course of RAGA, the parent generation scale is 400 ($n = 400$). The crossover probability is 0.80 (p_c =0.80). The mutation probability is 0.80 (p_m =0.80). The number of excellence individual is 20 (α =0.05). With several times accelerating, the best projection value under the condition of different water supplication can be carried out (Table 3).

The optimum irrigation system under non-sufficient irrigation of well irrigation rice in Sanjiang Plain is shown in Table 4. The relation between irrigated water quantity and relative yield is shown in Figure 1.

Table 3. The Results of RAGA-DP (Unit: mm)

	Q	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
1998	400	214.01	140.88	72.61	185.99	73.13	68.27	72.61	240.14	129.60	66.22	114.40	-49.54
1999	450	265.63	161.13	77.19	184.37	104.50	83.94	77.19	221.27	126.40	71.89	150.30	-48.31
	F	a_{13}	a_{14}	a_{15}	d_1	d_2	d_3	d_4	K_1	K_2	K_3	K_4	z
1998	0.9508	-46.32	-27.12	-65.00	24	7	4	9	92.39	26.81	12.35	28.69	14
1999	0.9509	-18.76	8.99	-65.00	22	9	7	11	80.41	33.35	21.70	36.58	10

Note: z —accelerated times.

Table 4. Optimum Irrigation System Under Non-sufficient Irrigation of Well Irrigation Rice in Sanjiang Plain

Year	Water supply (mm)	Irrigating water quantity of each phase. (mm)				Relative yield
		①	②	③	④	
1998	**0**					0.5620
	50	10.30	14.47	20.23	4.99	0.6398
	100	24.57	42.46	20.73	12.23	0.7002
	150	30.88	52.49	27.61	39.01	0.7690
	200	69.19	49.07	49.23	32.51	0.7949
	250	82.65	61.14	58.54	47.68	0.8340
	300	120.67	54.51	53.51	71.33	0.8756
	350	147.03	99.42	40.52	63.02	0.9021
	400	185.99	73.13	68.27	72.61	0.9508
	450	231.59	97.99	69.65	50.77	0.9685
	500	282.51	86.34	67.14	64.00	0.9927

1999	**0**					0.5765
	50	17.00	12.89	8.20	11.91	0.6564
	100	27.70	41.29	12.24	18.77	0.7222
	150	48.81	41.24	33.78	26.17	0.7698
	200	46.18	71.78	33.69	48.35	0.8061
	250	74.24	74.83	36.24	64.69	0.8444
	300	116.91	38.01	92.74	52.34	0.8685
	350	131.15	120.42	51.48	46.95	0.8863
	400	165.81	61.98	70.11	102.10	0.9227
	450	184.37	104.50	83.94	77.19	0.9590
	500	236.23	79.57	96.60	87.60	0.9628
	550	297.50	59.20	103.56	89.75	0.9989

5. Discussion

(1) When the irrigation norm is small, the rice yield increases along with the increased irrigation norm. At first, the increasing extent is great. When the irrigation norm increases more and more, the increasing extent reduces obviously. It means that the marginal benefit reduces. When the irrigation norm reaches to a certain value, it has no benefit for increasing yield through increasing water supply. The optimum irrigation system can't only describe the varied relation between rice yield and water supply, but also indicates the necessary irrigation norm in a certain typical year in order to reach fertility. Thus, wasting water resource can be avoided. The net duty of water is only 4500 m^3/hm^2 for well irrigation rice of Fujin area in Sanjiang Plain, and the relative yield can reach 95% or so. When the relative yield reaches 1.0, the net duty of water demands 5500 m^3/hm^2 in 1999 (middle drought year). In 1998 (normal year), the net duty of water is only 4000 m^3/hm^2, and the relative yield can reach 95% or so. If the relative yield reaches 1.0, the net duty of water demands only 5000 m^3/hm^2.

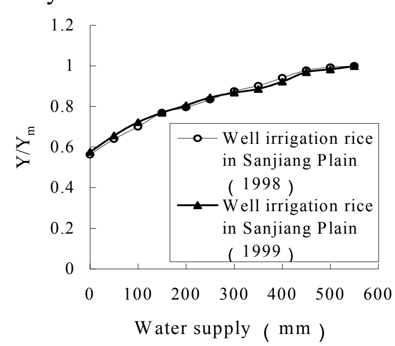

Figure 1. The Relation Between Water Supply Per Hm^2 and Relative Yield (Y/Y_m)

Taking consideration of the cost of input water and yield, although the yield reduces 5% or so, 15-20% of water can be saved.

(2) Because the optimum irrigation system can provide water for rice in every phase according to the synthetic influence to yield caused by water supply, the high yield by means of a small irrigation norm can be obtained. For example, the available rainfall during the growth period in Fujin area is 2069 m^3/hm^2 in 1999. The net duty of water that can satisfy the yield demand is 4500m^3/hm^2. The available rainfall and net duty of water are 6569 m^3/hm^2. According to the water saving experience in Sanjiang Plain, the water supply that can achieve good fertility is about 8000 m^3/hm^2. Thus, 1431 m^3/hm^2 of water can be saved (to save 17.9% of water). The maximum irrigation norm of traditional irrigating mode can reach 15000 m^3/hm^2, the minimum can reach 7500 m^3/hm^2, and the average irrigation norm is 11250 m^3/hm^2. Recently, many methods of water saving irrigation have been applied in Sanjiang Plain. That includes rice intermission irrigation, shallow, wet, dry and sun field combined together and any other water saving irrigation measurement through controlling water depth. These measurements can reduce the irrigation norm, and save water 30.7%. If the relative yield reaches 1.0, 5.4% of water can be saved based on the observation of water saving experience. It is obvious that optimum rice irrigation can save much resource water and bring considerable economical benefit.

(3) In recent years, people expended the area of well irrigation rice without an optimum irrigation system in place. The groundwater supply is lacking. It is more important than ever to develop and adopt an optimum irrigation system. In the old time, when we lacked water resource, we irrigated the "key water" according to our experience. However, the optimum irrigation system can precisely guide users how to distribute the limited water supply in different time according to different degree of water shortage. At last, the maximum yield and minimum reduction of output can be obtained. Especially in drought year, the water

saving benefit of optimum irrigation system is more significant.

(4) On the other hand, rainfall can influence the irrigation system.. The data in Table 1 are all observed results in 1998 and 1999. The rainfall, evapotranspiration and seepage quantity were used based on the data observed by field microclimate testing station. The available rainfall during the total growth period in 1999 is 206.9 mm (2069 m^3/hm^2), the best irrigation norm is 450 mm (4500 m^3/hm^2), and the available rainfall is a little more in 1998. The available rainfall during the total growth period is 265.6 mm (2656 m^3/hm^2), and is more than 58.4 mm (587 m^3/hm^2). Thereby, the best economical irrigation norm is 50 mm (500 m^3/hm^2) less than in 1999. It agrees with the actual conditions.

(5) The most important parameter is sensitive exponent λ_i in dynamic programming. It will be obtained by trial of non-sufficient irrigation. Because the value of λ_i includes the weight in the key irrigating phase, the objective function of dynamic programming includes the meanings of economy irrigation and the best yield reaching. The λ_i of the average of 1998 and 1999 is adoptable.

(6) With combining RAGA and DP, the author advanced the method of DPSA. By means of optimizing 15 parameters at the same time and adjusting the parameter distribution, the best results have been obtained in the study. The calculating speed and precision are enhanced obviously.

(7) The data in Table 3 and 4 are calculated results. Every parameter can be adopted as integer in practice.

(8) The RAGA-DP model defines the irrigated phase and the water distribution in each phase. However, it does not define the specific irrigating day. Therefore, more research needs to done in the future.

Acknowledge

The financial support is provided by Chinese National "863" High-Technique Programme (No. 2002AA2Z4251-09); China Postdoctoral Science Foundation (No. 2004035167); Heilongjiang Province Youth Foundation (No. QC04C28); Natural Science Fund in China. (No. 30400275)

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References

[1] Cui Y. The summarize of optimum providing water under non-sufficient irrigation. Irrigation and Drainage 2000;19(1):66-70.

[2] Guo Y, Li S. The best programming and management of irrigation & drainage engineering. Publishing Company of Water Conservancy and Electric power, Beijing, China. 1994:274-9.

[3] Jin J, Ding J. Genetic arithmetic and its application to water science. Sichuan University Publishing Company, Chengdu, China: 2000:42-7.

[4] Kang S, Zai H. Agricultural water management science. China Agricultural Press, Beijing, China. 1996:232-4.

[5] Li Y. The theory and technique of water saving irrigation. Water Conservancy & Electric Power University Publishing Company, Wuhan, China. 1999:81-99.

[6] Zhou M, Sun S. The theory of genetic arithmetic and its application. National defense industry publishing company, Beijing, China. 2000:4-7,37-8.

[7] Zhu T. The theory and technique of rice irrigation. Publishing Company of Water Conservancy and Electric Power In China, Beijing, China. 1998:222-4.