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Yubao Wang[1,2,3,4]
Pute Wu[1,2,3]
Xining Zhao[1,2,3]
Jiming Jin[4]

[1]Institute of Water Saving Agriculture in Arid regions of China, College of Water Resources and Architectural Engineering, Northwest A & F University, Yangling, P. R. China
[2]Key Laboratory for Agricultural Soil and Water Engineering in Arid Area of Ministry of Education, Northwest A & F University, Yangling, P. R. China
[3]National Engineering Laboratory for Crop Water Efficient Use, Yangling, P. R. China
[4]Departments of Watershed Sciences and Plants, Soils, and Climate, Utah State University, Logan, UT, USA

Research Article

Projection Pursuit Evaluation Model: Optimizing Scheme of Crop Planning for Agricultural Sustainable Development and Soil Resources Utilization

Planting structure influences the economic, social, and ecological benefits of crop farming as well as the use efficiency of water and arable land resources, and so crop planning (CP) benefits for agricultural sustainable development and soil resources utilization. The projection pursuit evaluation (PPE) model is put forward to solve the problem of selecting an optimizing scheme for CP by considering the indices of water-saving and economic, social, and ecological benefits. The real-coding-based accelerating genetic algorithm (RAGA) is introduced to accelerate the calculation process. The model can translate multi-indices into a single index by transforming high-dimensional data to low-dimensional space, which helps evaluate CP optimizing schemes. For example, the model is used to evaluate and select an optimal scheme of CP in the middle reaches of the Heihe mainstream basin in the arid area of northwest China. According to four criteria (high efficiency of resources use, economic rationality, social equity, and ecological security) 19 indices were chosen to evaluate 12 optimizing schemes of four kinds (economic-benefit, food-security, ecological-benefit, and water-saving programs) in 2006, 2020, and 2030. The result shows that, in the 3 years, the water-saving program is always the optimized scheme in an arid region with water deficiency and fragile ecology. The evaluated results match up to the developmental conditions of crop farming in recent years. Moreover, the direction of the optimal projection could reflect the weight and orientation of indices objectively and accurately.

Keywords: Crop planning; Evaluation; Heihe River basin; Projection pursuit evaluation model; Real-coding-based on accelerating genetic algorithm

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1 Introduction

Crop planning (CP) means to optimize the planting structure for ensuring maximum returns from every unit cultivated area [1]. Planting structure refers to the ratios among varieties, cultivation area, and output of crops within a certain region [2]. Planting structure influences not only the economic, social, and ecological benefits of crop farming, but also the use efficiency of water and arable land resources [3]. Therefore, the planting structure in China has been adjusted many times since 1949 [4]. Before the reform and opening-up (from 1949 to 1978), ''Grain is the key'' was emphasized because of poor food shortage; the cultivated area of grain crops accounted for 88.47 and 80.34% of total cultivated area in 1949 and 1978, respectively. After the reform and opening-up (from 1979 to the present), a scientific and reasonable Grain–Cash–Forage ternary planting structure was established step-by-step by achieving grain self-sufficiency through a quick increase of per-unit-area yield. During this period, the percentage of cultivated area taken up by grain crops reduced to 67.11% in 2006 [5].

There is a great deal of difference among the subareas in a large-scale region or a basin, and the demands of people in diverse subareas are also different; therefore, it is normal that more than one optimizing scheme of CP is required. How should a specific program be chosen and implemented from among so many optimized programs? An evaluation of the programs can resolve this problem. Moreover, the original optimizing schemes could be rectified through useful feedbacks like evaluating the results of the optimizing schemes or their aftereffects. However, CP, or the scheme selection, involves multi-dimensional harmonizing relationships among different subsystems and different levels of the complex giant social–economic–environmental system, and they are therefore complex-non-linear-decision problems [6]. Therefore, one of the most urgent problems that need to be solved for researchers is how to evaluate and choose the optimal scheme from the CP programs

Correspondence: Professor P. Wu, College of Water Resources and Architectural Engineering, Northwest A & F University,Yangling 712100, P. R. China
E-mail: gjzwpt@126.com; gjzwpt@vip.sina.com

Abbreviations: CP, crop planning; **PPE**, projection pursuit evaluation; **RAGA**, real-coding-based accelerating genetic algorithm while considering the indices of economic, social, and ecological benefits of the planting industry [6–29]. The multiple analysis method is a valid tool to treat this sort of high-dimensional data problem [7, 30, 31]. The traditional multiple analyses are based on the assumption that the samples conform to the general normal distribution, but the truth is that the distribution of evaluated schemes is not decided yet [7, 8]. A serial of principles and methods that have been proposed by domestic and foreign scholars played a positive role in evaluating the schemes of CP, such as the methods of composite index, Analytic Hierarchy Process (AHP), Delphi, gray correlation degree, matter-element analysis, fuzzy comprehensive evaluation, artificial neural network method, and so on [9–15]. However, most of these methods get a comprehensive value by giving weights to each index; hence, it is feasible to change the evaluation objectives by giving weights to subjective factors. Moreover, there is a shortage of structural evaluation of the contribution and direction of each index to the total objective [16]. The projection pursuit technology, which originated in the middle of 1970s, is a new statistical method for analyzing and treating high-dimensional data, especially non-normal and non-linear data, and it has the merits of steadiness, immunity, and high accuracy [17]. Therefore, a projection pursuit evaluation (PPE) model was used to resolve the problem of evaluating CP and selecting the optimized scheme, and the real-coding-based accelerating genetic algorithm (RAGA) with the function of global convergence was introduced to accelerate the calculation process in this paper. The process is first to translate multi-indices into a single index by transformation from high-dimensional data to a low-dimensional space with an acquired optimized projection direction. Next in the process is to calculate and identify the corresponding grade of the projection value by contrasting it with the calculation results of a standard sample, and thereby realize the evaluation of the optimizing scheme for CP [30, 31].

2 Modeling steps of PPE- RAGA

2.1 Normalizing evaluation indices of samples

Let $y(i)$ be the grade of a certain optimizing program, which is produced according to the grade criterion table of an optimizing program evaluation, and let $\{x^*(x,j)\ |i=1, 2, \ldots, n; j=1, 2, \ldots, p\}$ be the evaluation indices assemblage, where $x^*(i,j)$ represents the jth index value of the ith sample, n is the number of samples, and p is the number of indices. The normalizing the data can eliminate the magnitude and unify the scope of index variety [7, 16].

For a bigger the better index:

$$x(i,j) = \frac{x*(i,j) - x_{\min}(j)}{x_{\max}(j) - x_{\min}(j)} \tag{1}$$

For a smaller the better index:

$$x(i,j) = \frac{x_{\max}(j) - x*(i,j)}{x_{\max}(j) - x_{\min}(j)} \tag{2}$$

where $x_{\max}(j)$ and $x_{\min}(j)$ are the maximum and the minimum value of the jth index, respectively, and $x(i,j)$ is the sample set of the normalized indices.

2.2 Optimizing the projective index function *Q*(*a*)

The PPE model synthesizes the p dimension data $\{x(x,j)\ |i=1, 2, \ldots, n; j=1, 2, \ldots, p\}$ to one dimension projective value $z(i)$ with the projective direction of $\{a=a(1), a(2), \ldots a(p)\}$ by Eq. (3):

$$z(i) = \sum_{j=1}^{p} a(j)x(i,j) \tag{3}$$

where a is a unit length vector.

Then we can construct a mathematical relation according to the scatter-plot of $z(i)$ and $y(i)$. When projecting an objective value, the spreading characteristics of the projective values $z(i)$ should be as follows: The whole projective point groups should disperse as much as possible, while the partial projective points should concentrate as much as possible; it is best to centralize into a number of point groups. Based on the above demands, a projective index function can be designed as follows [18–21]:

$$Q(a) = S_z D_z \tag{4}$$

where S_z is standard deviation of n projective values $z(i)$, and D_z represents the partial density of projective values $z(i)$, namely:

$$S_z = \frac{\sqrt{\sum_{i=1}^{n} (z(i) - E(z))^2}}{n-1} \tag{5}$$

$$D_z = \sum_{i=1}^{n} \sum_{j=1}^{n} (R - r(i,j))u(R - r(i,j)) \tag{6}$$

where $E(z)$ is the average value of the series $\{z(i)\ |i=1, 2, \ldots, n\}$ and R is the window radius of partial density. The value of R should not only prevent the projective points contained in the window from being too few to avoid excessive moving-average deviation, but also ensure that it will not increase too much with the growth of the n-value. R can be assigned by a test, and we can let $R=0.1\ S_z$ in an actual mathematical operation; $r(i,j)$ is the distance between samples and is equal to $|z(i)-z(j)|$; $u(t)$ represents unit step function with $u(t)=1$ if $t\geq 0$ and $u(t)=0$ if $t<0$.

2.3 Optimizing the projective index function and determining the optimal projective direction

The projective index function $Q(a)$ alters only with the changes of projective direction after the index sample is given. The optimal projective direction can be estimated by resolving the following optimal Eq. (7):

$$\begin{aligned} &\max(Q(a)) = S_z D_z \\ &\text{s.t.} \sum_{j=1}^{p} a^2(j) = 1 \quad 0 \leq a(j) \leq 1 \end{aligned} \tag{7}$$

Equation (7) is a complex and non-linear optimization problem, where the optimized variable is $a(j)$ with p dimensions. According to the definition of $u(t)$ and $r(i,j)$, $Q(a)$ is discontinuous or non-differentiable, so it is difficult to resolve the problem by traditional methods. As a kind of general optimization method based on the mechanics of natural selection and natural genetics, RAGA can be applied to deal with the optimization problem easily and effectively [19].

2.4 Grade evaluation

All the projective values of $z^*(i)$ could be obtained by Eq. (3) with the substitution of optimal projective direction a^*, and then the grade of samples could be evaluated by the grade evaluation criteria.

3 Instance analysis

Taking the middle reaches of the Heihe mainstream basin (an arid area of northwest China) as an example, the anterior PPE-RAGA model was applied to choose the optimized CP. The Heihe River basin is located in the center of the Eurasian continent and is therefore far from the oceans. Hence, it has a typical continental climate: Dry environment with little precipitation, strong evaporation, large temperature differences, abundant sunlight resources, etc. The Heihe River basin is an important production base for commodity grains, vegetables, melons, fruits, and crop seeds in western China. For a long time, because of continuous pressure from population growth and excessive economic development activities, the vulnerable local water resources and ecological conditions have continued to worsen. Drought and environmental deterioration have become the bottleneck factors for social and economic development, and have become a serious threat to the sustainability of social and economic development in the basin. The middle reaches of the Heihe mainstream basin, which contains the three counties Ganzhou, Linze, and Gaotai, is the most important planting region and the uppermost water consumption district in the basin. In 2006, the population in the region was 39.5% of the basin's total, the arable land was 33.1%, valid irrigation areas was 43.0%, total water consumption was 45.3%, agricultural water consumption was 51.4%, grain yield was 46.4%, and total output value of planting was 46.6%. The amount of usable surface water is $12.07 \times 10^8\,m^3$ according to the water resources assignment scheme in the Heihe River basin, and the amount of mineable groundwater is $1.76 \times 10^8\,m^3$; therefore, the total usable water resources is $13.83 \times 10^8\,m^3$ in the region. However, the actual water consumption was $16.10 \times 10^8\,m^3$ in 2006, of which the irrigation water occupied $14.00 \times 10^8\,m^3$. Therefore, not only was the water resources in the lower reaches of the basin occupied, but also the resources of the ecology in the region. What's more, the groundwater was overexploited and the regional ecology worsened. At the same time, the planting structure was not reasonable enough, having low crop water use efficiency as well as a disparity between crop water requirements and incoming river water processes. For example, usually the crop water requirement is very large but the runoff is comparatively small in late spring and early summer, which causes serious agricultural production losses [3].

Four programs were initially developed according to the actual situation in 2006. They are economic-benefit (P_1), food-security (P_2), ecological-benefit (P_3), and water-saving (P_4) programs. According to predictions, four kinds of programs were also made initially for 2020 and 2030, which are, respectively, P_5–P_8 and P_9–P_{12}.

3.1 The appreciation index system

A rational CP system should be balanced among the economic rationality, social equity, ecological security, and resource use effi-

Table 1. The appreciation system for optimizing programs for CP

Objective layer	Criteria layer	Index layer	
Reasonable degree of planting structure	Resource use efficiency	Repeated use rate of water resources (%) I_1	Total irrigation water use amount/water taken without the return
		Water use efficiency (kg m^{-3}) I_2	Total crop yield/irrigation water use amount
		Monthly maximum water-shortage rate (%) I_3	(Crop water requirement -available irrigation water)/the prior
		Annual precipitation use efficiency (%) I_4	Annual precipitation use amount/annual rainfall
		Multiple crop index (%) I_5	Crop cultivated area/total arable land area
	Economic rationality	Annual per capita net planting income of farmer (Yuan) I_6	Annual net planting income in rural area/rural population
		Net planting output per unit volume water (Yuan,·m^{-3}) I_7	Net output of planting industry/irrigation water use amount
		Net output of planting per unit area (Yuan,·hm^{-2}) I_8	Net output of planting industry/total arable land area
		Ratio of output to investment I_9	Output/total cost
	Social equity	Per capita grain yield (kg) I_{10}	Total grain yield/total population
		Effective irrigation ratio of arable land (%) I_{11}	Effective irrigation area/total arable land area
		Proportion of agricultural water use (%) I_{12}	Agricultural water use amount/total water use
	Ecological security	Crop shade density (%) I_{13}	Weighted average shade density during the growth period
		Crop growth period (d) I_{14}	Days of crop growth period
		Ratio of Salinization of arable land (%) I_{15}	Salinization of arable land area/total arable land area
		Rate of groundwater overdraft (%) I_{16}	(Exploitation quantity − exploitable amount)/the prior
		Soil erosion modulus of arable land ($\times 10^3$ kg km^{-2}) I_{17}	Soil erosion amount/total arable land area
		Fertilizer use amount per unit area (kg km^{-2}) I_{18}	Total fertilizer use amount/total arable land area
		Pesticides use amount per unit area (kg km^{-2}) I_{19}	Total pesticides use amount/total arable land area

Table 2. The initial values of appreciation indices of optimizing scheme for CP in 2006, 2020, and 2030

Index	2006				2020					2030		
	P_1	P_2	P_1	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
I_1	126	124	127	128	140	137	140	143	147	144	146	150
I_2	1.05	1.00	1.00	1.15	1.7	1.5	1.5	1.8	2.2	2	2	2.3
I_3	23	24	21	20	15	17	13	12	9	11	7	6
I_4	29	27	31	32	36	34	38	39	40	38	42	43
I_5	105	106	105	106	110	111	110	111	115	116	115	116
I_6	2655	2439	2444	2686	4050	3711	3748	4154	6257	5837	5886	6487
I_7	1.09	1.04	1.05	1.19	1.65	1.37	1.38	1.61	1.71	1.61	1.62	1.9
I_8	12 951	11 896	11 921	14 064	14 580	13 358	13 492	16 115	15 597	14 549	14 672	17 332
I_9	1.5	1.3	1.3	1.5	1.9	1.6	1.6	1.9	2.2	2	2	2.2
I_{10}	763	980	690	765	756	966	681	758	799	1053	736	806
I_{11}	87	86	88	90	92	91	93	95	95	95	97	98
I_{12}	94	95	92	87	86	87	84	79	80	81	78	74
I_{13}	29	28	33	31	32	31	38	35	34	33	40	37
I_{14}	193	188	218	196	197	192	222	201	200	194	228	204
I_{15}	7	8	5	7	5	6	3	5	3	4	1	2
I_{16}	11	12	10	8	7	8	6	5	3	4	2	1
I_{17}	7	7	5	6	4	4	3	3	3	3	1	1
I_{18}	1725	2025	1425	1650	1275	1575	1050	1125	825	1125	675	750
I_{19}	22.5	21	12	16.5	16.5	15	7.5	10.5	12	9	4.5	6

ciency to realize maximum economic, social, and ecological benefits, as well as the high use efficiency of agricultural resources, especially the water resources [22–29]. Therefore, a reasonable degree of planting structure was seen as the objective layer in this paper; the economic rationality, social equity, ecological security, and resource use efficiency were seen as the four criteria layers and 19 basic indicators were selected as the index layer to constitute the evaluation system of optimizing programs for CP, as shown in Tab. 1.

3.2 The initial values of appreciation indices and their normalization

Tables 2 and 3 shows the initial values and the normalized values of the appreciation indices for CP optimizing schemes in 2006, 2020, and 2030, respectively. The cultivation area ratio of grain crops to cash crops to forage crops of scheme P_1 in 2006 is 55:41:4, P_2 is 60:36:4, P_3 is 53:39:8, and P_4 is 49:47:4. The cultivation area ratio in 2020 for P_5 is 51:44:5, P_6 is 56:39:5, P_7 is 49:42:9, P_8 is 44:51:5; in 2030, P_9 is 50:45:5, P_{10} is 55:39:6, P_{11} is 48:42:10, and P_{12} is 43:51:6.

3.3 The appreciation standard of indices

The appreciation standard of the indices must be set out to evaluate the optimizing schemes of CP after the appreciation system has been chosen and the index value has been given. The establishing principle of an appreciation standard for a diverse index is different: for the positive indicators, we can look to the limit or to the attainable maximum under current conditions as the most reasonable grade

Table 3. The normalized values of appreciation indices of optimizing scheme for CP in 2006, 2020, and 2030

Index	2006				2020				2030			
	P_1	P_2	P_1	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
I_1	0.52	0.48	0.54	0.56	0.80	0.74	0.80	0.86	0.94	0.88	0.92	1.00
I_2	0.33	0.30	0.30	0.38	0.65	0.55	0.55	0.70	0.90	0.80	0.80	0.95
I_3	0.43	0.40	0.48	0.50	0.63	0.58	0.68	0.70	0.78	0.73	0.83	0.85
I_4	0.38	0.34	0.42	0.44	0.52	0.48	0.56	0.58	0.60	0.56	0.64	0.66
I_5	0.45	0.50	0.45	0.50	0.70	0.75	0.70	0.75	0.95	1.00	0.95	1.00
I_6	0.33	0.30	0.30	0.34	0.55	0.49	0.50	0.56	0.89	0.82	0.83	0.92
I_7	0.35	0.32	0.33	0.40	0.63	0.49	0.49	0.61	0.66	0.61	0.61	0.75
I_8	0.60	0.54	0.54	0.67	0.70	0.63	0.64	0.79	0.76	0.70	0.71	0.87
I_9	0.39	0.28	0.28	0.39	0.61	0.44	0.44	0.61	0.78	0.67	0.67	0.78
I_{10}	0.64	0.82	0.58	0.64	0.63	0.81	0.57	0.63	0.67	0.88	0.61	0.67
I_{11}	0.74	0.72	0.76	0.80	0.84	0.82	0.86	0.90	0.90	0.90	0.94	0.96
I_{12}	0.08	0.06	0.13	0.23	0.25	0.23	0.29	0.40	0.38	0.35	0.42	0.50
I_{13}	0.48	0.45	0.58	0.53	0.55	0.53	0.70	0.63	0.60	0.58	0.75	0.68
I_{14}	0.73	0.68	0.98	0.76	0.77	0.72	1.02	0.81	0.80	0.74	1.08	0.84
I_{15}	0.30	0.20	0.50	0.30	0.50	0.40	0.70	0.50	0.70	0.60	0.90	0.80
I_{16}	0.45	0.40	0.50	0.60	0.65	0.60	0.70	0.75	0.85	0.80	0.90	0.95
I_{17}	0.53	0.53	0.67	0.60	0.73	0.73	0.80	0.80	0.80	0.80	0.93	0.93
I_{18}	0.23	0.10	0.37	0.27	0.43	0.30	0.53	0.50	0.63	0.50	0.70	0.67
I_{19}	0.12	0.18	0.53	0.35	0.35	0.41	0.71	0.59	0.53	0.65	0.82	0.76

Table 4. The appreciation standard of the indices for the optimizing scheme of CP

Index	S_1	S_2	S_3	S_4	S_5
I_1	<110	110–120	120–130	130–140	>140
I_2	<0.8	0.8–1.2	1.2–1.6	1.6–2.0	>2.0
I_3	>30	30–20	20–10	10–5	<5
I_4	<20	20–30	30–40	40–50	>50
I_5	<100	100–104	104–108	108–112	>112
I_6	<1000	1000–2500	2500–4000	4000–5500	>5500
I_7	<0.8	0.8–1.2	1.2–1.6	1.6–2.0	>2
I_8	<7500	7500–10 500	10 500–13 500	13 500–16 500	>16 500
I_9	<1.0	1.0–1.4	1.4–1.8	1.8–2.2	>2.2
I_{10}	<100	100–200	200–300	300–400	>400
I_{11}	<80	80–85	85–90	90–95	>95
I_{12}	>90	90–80	80–70	70–60	<60
I_{13}	<25	25–30	30–35	35–40	>40
I_{14}	<180	180–190	190–200	200–210	>210
I_{15}	>8	8–6	6–4	4–2	<2
I_{16}	>12	12–9	9–6	6–3	<3
I_{17}	>10	10–7	7–4	4–1	<1
I_{18}	>1875	1875–1500	1500–1125	1125–750	<750
I_{19}	>21.0	21.0–16.5	16.5–12.0	12.0–7.5	<7.5

standard according to the index itself and the restriction of objective material conditions; for the negative indicators, the minimum of theoretical or actual value could be the most reasonable grade standard [20]. Contrary to this, we determined the most unreasonable grade standard. The other three grade standards were divided equally in the interval between the most unreasonable and most reasonable grades as the standards for more unreasonable, ordinary, and more reasonable. The grade standard of the appreciation indices is shown in Tab. 4.

Then we selected the right-end point values of all the grade standards to generate five evaluation standard samples. In order to meet the calculation precision, the other 100 index samples were formed randomly and evenly in the grade intervals to constitute evaluation index samples $x^*(i,j)$. After the indices had been normalized to $x(i,j)$, $i = 1, 2, \ldots, 109$; $j = 1, 2, \ldots, 19$, a RAGA-PPE model was programmed with the Matlab tool. Also, the objective functions and restrictive conditions were programmed to evaluate the 105 samples with 19 dimensions according to five grades. In the program the initial population size of parents is 400, the crossing probability $p_c = 0.80$, mutation probability $p_m = 0.80$, the number of prior individuals is 25, and the accelerating time is 20.

The calculation outputs the optimal projective vector $a = [0.2396, 0.2405, 0.224, 0.2411, 0.2424, 0.2743, 0.2394, 0.2177, 0.2664, 0.2466, 0.1201, 0.2486, 0.1790, 0.1196, 0.2405, 0.2303, 0.2404, 0.2405, 0.2386]$. After finding this vector, we can get the corresponding projective value $z(i) = [0.9155, 1.7289, 2.5422, 3.3160, 4.2896]$ with Eq. (3). Figure 1 is the scatter-plot of standard samples by corresponding to the five evaluating standards of most unreasonable, more unreasonable, ordinary, more reasonable, and most reasonable to the grade levels of 1–5, respectively. Then we can acquire the mathematical relation of PPE model of $y = f(z)$ from Fig. 1.

3.4 Analysis of evaluation results

Evaluating the 12 optimizing schemes of CP by the same methods comprehensively, we acquired $a = [0.2669, 0.3320, 0.2438, 0.1513, 0.3171, 0.3333, 0.1949, 0.1106, 0.2342, 0.0290, 0.1099, 0.1970, 0.0995, 0.0926, 0.2983, 0.2716, 0.1966, 0.2603, 0.2831]$, corresponding projective value $z(i) = [1.5277, 1.3937, 1.7878, 1.7892, 2.3754, 2.1621, 2.5312, 2.6337, 3.0577, 2.8909, 3.2294, 3.3765]$, and also the corresponding $y = [1.7306, 1.5658, 2.0573, 2.0591, 2.8113, 2.5366, 3.0114, 3.1422, 3.6728, 3.4667, 3.8805, 4.0540]$ according to the mathematical relation of $y = f(z)$ from Fig. 1. Thus we could figure out the grade level of all the optimizing schemes as shown in Fig. 2 according to the comprehensive evaluation results.

The optimal projective direction reflects the weight of each index. The annual per capita net planting income of farmers, I_6, is the index with maximum weight (0.3333) in vector a. It manifests that the planting industry, being a very important income source, should first seek to improve farmers' earnings in the CP. Water use efficiency with a value of 0.3320 in a is the second most important index, which proves that crops with high WUE should be a priority in arid and water-deficient areas. Multiple-crop index is the third most important with a value of 0.3171 in a, which explains that it is important to optimize the spatial and temporal distribution of crops to enhance the utilization and output ratio of per unit area arable land in the CP.

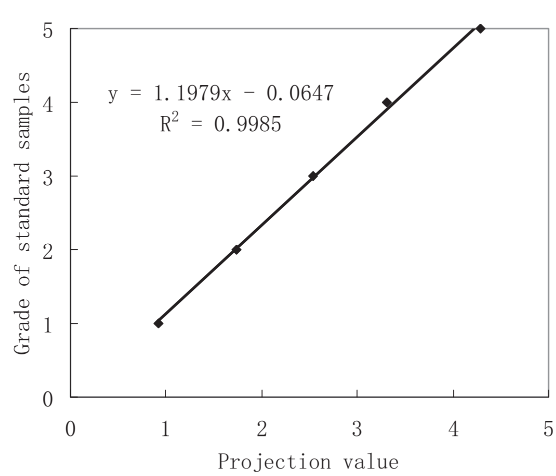

Figure 1. Relationship of projection value and grade.

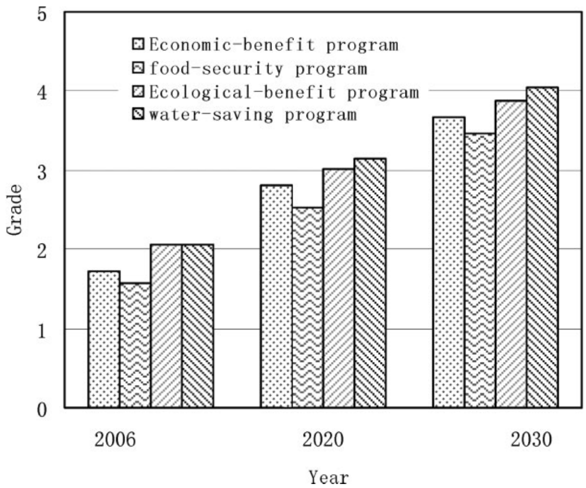

Figure 2. The grade of all the programs in different level years.

Figure 2 shows that the descending order of optimization schemes are the same throughout the water-saving, ecological-benefit, economic-benefit, and food-security programs, which proves that deficient water resources and fragile ecologies are bottleneck factors of the planting-industry's development in the northwest arid inland river basin, and that regional sustainable development can be ensured only by using water-saving methods [17–29]. Therefore, the water-saving program is preferred for the development of regional cropping. The ecological-benefit program is the second-best one, which means that we should moderate returning farmland to forest and grassland, and appropriately increase the cultivation area of forage crops according to the developing demand of livestock. The economic-benefit program is the third-best one, which indicates that pursuing only the maximum economic benefit is not yet a suitable cropping development mode for the water-short area. The food-security program is the worst one, which demonstrates that the single-crop farming mode, which only meets food demand, is irrational for the region.

In 2006, the programs of P_1 and P_2 belong to the more unreasonable grade level. The programs of P_3 and P_4 pertain to ordinary grade, but the grade value y is very close to the boundary between grades of more unreasonable and ordinary, which evidences that the adjustment of planting structure and corresponding water-saving measures have achieved certain results in recent years; but, overall, the planting industry was underdeveloped and water-saving level was low, and there is still much room for improvement. In 2020, the program of P_5 and P_6 are attributed to an ordinary grade, and P_7 and P_8 appeared to be more reasonable ones, which indicate that the cropping system will become rational overall. The cultivation area ratio among grain crops, cash crops, and forage crops is basically concerted, and corresponding water-saving measures will achieve considerable results. In 2030, the program P_{12} was attributed to the most reasonable grade, but all the others belong to the more reasonable grade, which means that the cropping system tends toward perfection, the ternary planting structure will be harmonized, and the corresponding water-saving measures will develop greatly.

Based on the above analysis, we can confirm that the evaluating index weight and results output by the RAGA-PPE model match well with the regional actual conditions, so the accuracy of the model was verified.

4 Conclusion

(1) The evaluation of the optimizing scheme or the aftereffect is an important component of CP. The reasonable degree of planting structure was seen as the objective layer; the economic rationality, social equity, ecological security, and resource use efficiency were used as four criteria layers; and 19 basic indicators were selected as the index layer to constitute the evaluation system of optimizing programs for CP. According to the evaluation results of the four sorts of optimizing schemes in 2006, 2020, and 2030 (which were economic-benefit, food-security, ecological-benefit, and water-saving programs), water-saving programs are consistently preferred for the arid and water-short region in northwest China.

(2) As the RAGA-PPE model was used to resolve the problem of evaluating CP (a problem which is non-normal, non-linear, and high-dimensional), it could project high-dimensional data to low-dimensional space and then reveal the structural features through the distribution structure of projective scatter plots in the low-dimensional space, or it could construct a mathematical model to predict systematic outputs based on the scatter plot of projective value and model output. The schemes of CP can be evaluated by Matlab programming conveniently, swiftly, and accurately.

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