Asian Agricultural Research 2022, 14 (6): 37 – 40 DOI: 10.19601/j.cnki.issn1943 – 9903.2022.06.009

Analysis and Optimization of Crop Planting Structure in Ningxia

Qing WANG, Huaru LIU, Dongpu FENG *

School of Civil Engineering and Hydraulic Engineering, Ningxia University, Yinchuan 750021, China

Abstract [**Objectives**] To analyze and optimize the crop planting structure in Ningxia based on the shortage of water resources and the large proportion of agricultural water consumption in Ningxia. [**Methods**] The change trend of crop planting area and planting structure in Ningxia in 2004 – 2018 was analyzed, and a multi-objective optimization model was constructed with the objectives of maximum crop profit and minimum water demand. The STEM method was applied to solve the problem, and the optimization scheme of crop planting in Ningxia was obtained. [**Results**] In Ningxia in 2004 – 2018, the planting area showed the characteristics of "increase-decrease-increase"; the area and proportion of cash crops were increasing, and the proportion of grain crops was gradually decreasing, but the proportion of crops with high water consumption was still high. After the planting structure was optimized, the economic benefit was increased by 34.85×10^8 yuan, and the water demand was reduced by 3.9×10^8 m^3. [**Conclusions**] Under the premise of ensuring food security, the optimized scheme not only saves water resources but also obtains higher economic benefits. It provides a reference for alleviating water shortage and increasing farmers' income.

Key words Multi-objective optimization, Planting structure optimization, STEM method

1 Introduction

Because of drought and little rainfall, Ningxia is one of the most water-scarce provinces in China, but its agricultural water consumption accounts for 84.8% of the total water consumption[1]. Especially, crops with high water consumption such as maize and rice have a large planting area, which intensifies the contradiction between supply and demand of water resources. Therefore, optimizing and adjusting the crop planting structure is of great significance to both food security and water resources security of Ningxia.

The optimization of agricultural planting structure is an effective measure to alleviate the contradiction between agricultural water supply and demand and improve the efficiency of water resources utilization[2]. In recent years, some scholars have carried out extensive studies on the optimization of crop planting structure. In view of the current shortage of water resources in the Hetao Irrigation District of Inner Mongolia, Guo Ping *et al.*[3] applied water footprint to multi-objective optimization of water resources, and used the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method and the coupled fuzzy hierarchy method to evaluate the optimization plan. Their results provided a decision support for local adjustment of planting structure. Deng Lingzhi *et al.*[4] used the C-PAC model to analyze the evolution of planting structure in Guizhou Province in the period of 1949 to 2013, and discussed the optimization strategies of planting structure. Tan Qian *et al.*[5] established the MRPWU agricultural water resources optimal allocation model for arid and semi-arid regions, and the optimization results show that the MRPWU model can improve the weight uncertainty of the optimization model, and it can save water and improve efficiency through properly reducing the planting area. With the aid of the linear programming model and Lingo software, Zhang Xicheng[6] studied the crop planting structure in the Kaidu-Kongque River Watershed, and the optimized scheme has significant water-saving and benefit effects.

The STEM method is a method for solving multi-objective single-level programming problems, and has good interaction and advantages in dealing with economic and policy optimization[7]. However, this method has little application in the optimization of planting structure. Therefore, in this study, we constructed a multi-objective optimization model for the crop planting situation in Ningxia, and used the STEM method to solve it. Through the optimization scheme of planting structure, it is expected to alleviate the contradiction between supply and demand of water resources in Ningxia, and provide a reference for promoting efficient utilization of water resources and sustainable agricultural development.

2 Materials and methods

2.1 Overview of the research area Ningxia Hui Autonomous Region covers a total area of 66 400 km^2. It is located at 35°14′ – 39°23′ N and 104°17′ – 107°39′ E. Its terrain is high in the south and low in the north. Ningxia is arid and less rainy, the evaporation intensity is high. Rainfall is mainly concentrated from June to September. The spatial and temporal distribution of water resources is uneven, and the problem of resource water shortage is very prominent.

2.2 Data source The crop irrigation quota used in this study came from the *Water Quota for Related Industries in Ningxia Hui Autonomous Region* (2020)[1]. The crop income and cost were selected from the *2019 National Agricultural Product Cost and Benefit Data Compilation*[8], and the planting area data were selected from the *Ningxia Statistical Yearbook*[9].

Received: March 10, 2022 Accepted: May 18, 2022

Qing WANG, master candidate, research direction: hydrology and water resources.

* Corresponding author. Dongpu FENG, PhD., lecturer, research direction: hydrology and water resources.

Table 1 Basic data of various crops in Ningxia

Type	Unit yield kg/ha	Net profit yuan/kg	Water demand m^3/ha
Rice	8 266.9	0.42	12 450
Wheat	3 143.2	0.2	4 650
Maize	7 677.5	0.16	4 200
Beans	1 378.4	0.24	4 400
Tubers	4 014.6	0.24	2 400
Oil crops	2 028.6	0.07	3 000
Medicinal crops	3 644.3	6.02	3 000
Vegetables	44 334.2	0.74	4 500
Melons and fruits	26 599.2	1.59	4 200

2.3 Research methods On the basis of ensuring the existing farmland area and basic grain planting area, we established a multi-objective optimization model to achieve the maximum economic benefit of crops and the minimum water consumption, and used the STEM method to solve the problem.

2.3.1 Determination of decision variables. We took the planting area of 9 main crops in Ningxia as the decision variables, that is, rice, wheat, maize, beans, tubers, oil crops, medicinal crops, vegetables, melons and fruits, expressed as $X_1 - X_9$, respectively.

2.3.2 Determination of objective function. In this study, we took the highest benefit and the lowest water demand as the objective function, as follows:

$$\max N = \sum_1^9 A_i \times B_i \times X_i \quad (1)$$

$$\min M = \sum_1^9 C_i \times X_i \quad (2)$$

where A_i denotes crop yield, expressed in kg/ha; B_i denotes the net profit, expressed in kg/yuan; X_i denotes the crop planting area, expressed in ha; C_i denotes water demand of crop, expressed in m^3/ha.

2.3.3 Constraint conditions. (i) Planting area constraint. The average of the total planting area in 2010 – 2018 was used as the area constraint.

$$\sum X_i \leqslant 1\ 013\ 100 \quad (3)$$

(ii) Water consumption constraint.

$$M < W \quad (4)$$

where W is the minimum value of agricultural water consumption in the past ten years.

(iii) Constraint of planting area of grain crops. In order to ensure food security, grain crops must reach a certain proportion. Through the analysis of the planting area of grain crops in the past two decades, we determined the proportion of the largest and smallest areas of food.

$$A \times 0.59 \leqslant \sum_1^9 X_i \leqslant A \times 0.63 \quad (5)$$

(ix) Non-negative constraint.

$$X_i > 0 \quad (6)$$

(v) Rice planting area constraint.

Considering the 14^{th} Five-Year Plan and local conditions in Ningxia, we determined the rice planting area to be 14 000 ha in this study.

2.3.4 Solution based on STEM method. The STEM method solves the multi-objective optimization model through multi-parameter optimization step by step calculation, and uses trial calculation and iterative calculation to solve the multi-objective optimization model. The method has the characteristics of strong global optimization ability and good convergence. The specific process is as follows:

Assume there is a linearity with k objectives:

$$V \to \max_{x \in R} C \times X \quad (7)$$

where $R = \{X/AX \leqslant b, X \geqslant 0\}$, A is $m \times n$ matrix, C is $k \times n$ matrix.

The calculation steps to solve are as follows:

Step 1: solve the solutions of k single-objective linear programming problems separately.

$$\max_{x \in R} C^j \times X \ (j = 1, 2, \cdots, k) \quad (8)$$

The obtained optimal solution X^j, $(j = 1, 2, \cdots, k)$ and the corresponding $C^j X^j$, and made a table $Z = Z_i^j$, where:

$$Z_i^j = C^i \times X^j \quad (9)$$

$$Z_j^j = \max_{x \in R} C^j X = C^j X^j = M_j \quad (10)$$

Step 2: calculate the weighting coefficient.

where M_j is the deviation magnitude of the objective function, $M_j = \min Z_i^j$, $j = 1, 2, \cdots, k$. In order to find out the relative deviation of the objective value and eliminate the problem of different dimensions of different objective values, we conducted the following processing.

$$\text{When } M_j > 0,\ \alpha = \frac{M_j - m_j}{m_j} \times \frac{1}{\sqrt{\sum_{i=1}^n (C_i^j)^2}} \quad (11)$$

$$\text{When } M_j < 0,\ \alpha = \frac{m_j - M_j}{M_j} \times \frac{1}{\sqrt{\sum_{i=1}^n (C_i^j)^2}} \quad (12)$$

After normalization, we obtained the weight coefficient:

$$\pi = \frac{\alpha}{\sum_{j=1}^k \alpha_j} \quad (0 \leqslant \Pi_j \leqslant 1,\ \Sigma \Pi_j = 1,\ j = 1, 2, \cdots, k \quad (13)$$

Step 3: construct a linear programming problem and solve it.

$$Lp(1) \begin{cases} \min \lambda \\ \lambda \geqslant (M_i - c^i x)\pi_i,\ i = 1, 2, \cdots, k \\ x \in R,\ \lambda \geqslant 0 \end{cases} \quad (14)$$

Assuming that the obtained solution is $x^{(1)}$, then the corresponding k objective value is $c^1 x^{(1)} c^2 x^{(2)}, \cdots, c^k x^{(k)}$. If $x^{(1)}$ is the ideal solution of the decision maker, its corresponding k objective values are $c^1 x^{(1)}$, $c^2 x^{(1)}$, $\cdots$, $c^k x^{(1)}$. At this time, the decision maker compares the objective value of , if the decision maker is satisfied, he can stop calculation; if the difference is too far, he should consider appropriate corrections. If the decision maker considers to be lenient on the j^{th} objective, that is, make a little concession, reduce or increase a Δc^j, and change the constraint set R to

$$R^1 \begin{cases} c^j x \geqslant c^j x^{(1)} - \Delta c^j \\ c^i x \geqslant c^i x^{(1)},\ \bar{i} \neq j \\ x \in R \end{cases} \quad (15)$$

Let the weight coefficient of the j^{th} objective $\pi = 0$, which means reducing the requirements of this objective. Then solve the following problems:

$$Lp(2) \begin{cases} \min \lambda \\ \lambda \geqslant (M_i - c^i x)\pi_i,\ i = 1, 2, \cdots, k \\ x \in R^1,\ \lambda \geqslant 0 \end{cases} \quad (16)$$

Repeat the steps until the results are satisfied.

3 Results and analysis

3.1 Planting area and structure analysis From Fig. 1, it can be seen that the total planting area of crops in Ningxia shows a trend of "increase-decrease-increase". By the end of 2018, the planting area and proportion of maize in grain crops had been increasing rapidly, while the planting area and proportion of wheat, tubers and beans had dropped significantly, and the fluctuation of rice planting area had increased slightly. Among cash crops, compared with 2004, the planting area and proportion of oil crops decreased significantly, while medicinal crops increased by 5 times; vegetables, melons and fruits and feed increased by 2.6, 3.4 and 1.8 times, respectively. From the change of planting structure, it is found that both the planting area and proportion of cash crops were increasing, while the proportion of grain was gradually decreasing. This is conducive to increasing farmers' economic income and forming a diversified planting pattern, but the proportion of crops such as rice and maize with high water consumption was still relatively high.

3.2 Optimization of planting structure Through solving the model, we obtained the optimization scheme of planting structure in Ningxia, and compared and analyzed the current situation of annual average planting area in Ningxia. After the planting structure is optimized, the economic benefit was increased by 34.85×10^8 yuan, the water demand was reduced by 3.9×10^8 m^3, and the net output value was increased by 31.46×10^8 yuan. Specifically, the rice planting area decreased by 64 818 ha, water demand decreased by 8.07×10^8 m^3; wheat planting area decreased by 67 688.6 ha, water demand decreased by 3.15×10^8 m^3; maize planting area increased by 119 411.5 ha; tubers planting area decreased by 81 555.2 ha, water demand decreased by 1.96×10^8 m^3, net output value decreased by 0.78×10^8 yuan; the vegetable planting area increased by 70 582.5 ha, the water demand increased by 3.18×10^8 m^3, and the net output value increased by 23.15×10^8 yuan; the fruit planting area increased by 32 689.5 ha, the water demand increased by 1.37×10^8 m^3, and the net output value increased by 13.82×10^8 yuan. The adjustment of oil crops, beans and medicinal crops was not significant. Although vegetable and fruit cultivation consumed a lot of water, the economic benefits were very high, which is conducive to increasing the economic income of local people.

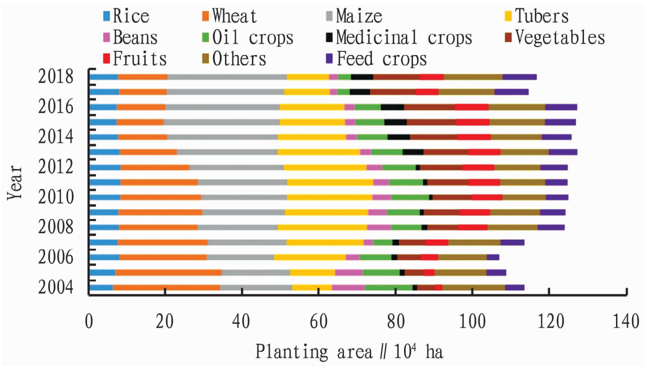

Fig. 1 Changes in crop planting area and structure in Ningxia in 2004 – 2018

Table 2 Comparison of current situation and optimized scheme of planting structure in Ningxia

Crop type	Current situation				Optimized scheme			
	Planting area ha	Proportion %	Water demand 10^8 m^3	Net output value 10^8 yuan	Planting area ha	Proportion %	Water demand 10^8 m^3	Net output value 10^8 yuan
Rice	78 818.0	7.78	9.81	2.74	14 000	1.38	1.74	0.49
wheat	147 688.6	14.58	6.87	0.93	80 000	7.90	3.72	0.50
Maize	276 744.5	27.32	11.62	3.40	396 156	39.10	16.64	4.87
Beans	29 565.8	2.92	1.30	0.10	27 000	2.67	1.19	0.09
Tubers	171 555.2	16.93	4.12	1.65	90 000	8.88	2.16	0.87
Oil crops	68 786.2	6.79	2.06	0.10	63 268	6.24	1.90	0.09
Medicinal crops	43 234.5	4.27	1.30	9.49	42 696	4.21	1.28	9.37
Vegetables	119 417.5	11.79	5.37	39.18	190 000	18.75	8.55	62.33
Melons and fruits	77 310.5	7.63	3.25	32.70	110 000	10.86	4.62	46.52
Total	1 013 120.8	100	45.70	90.27	1 013 120	100	41.80	125.12

4 Conclusions

In this study, we analyzed the changes of crop planting area and structure in Ningxia in 2004 – 2018, established a multi-objective optimization model, and solved it by STEM method, finally arrived at the following conclusions. (i) There was no obvious trend in the total planting area of grain crops, and each grain crop varied greatly. The total planting area of rice showed a stable trend, while wheat and beans showed a downward trend. Maize and tubers planting area showed an increasing trend. The total planting area of cash crops was on the rise. Among the cash crops, oil crops decreased slightly; the planting area and proportion of medicinal crops melons, fruits and vegetables increased greatly. (ii) The optimized planting scheme was consistent with the overall planning of Ningxia. The optimized planting structure reduced crops with high water consumption and low economic benefits, and increased crops with high economic benefits. In addition, the optimized planting scheme not only saved water resources, but also improved economic benefits, and the planting area of each crop was also in line with the future agricultural development direction of Ningxia.

References

[1] Ningxia Water Conservancy Department, Ningxia Hydrology and Water Resources Survey Bureau. 2020 Water Resources Bulletin of Ningxia Hui Autonomous Region[R]. Yinchuan: Ningxia Water Conservancy Department, Ningxia Hydrology and Water Resources Survey Bureau, 2020. (in Chinese).

[2] YANG SL, WANG HM, TONG JP, *et al.* Impacts of environment and human activity on grid-scale land cropping suitability and optimization of planting structure, measured based on the MaxEnt model[J]. Science of the Total Environment, 2022, 155356.

[3] GUO P, ZHAO M, ZHANG Y, *et al.* Optimization and evaluation of multi-objective planting structure in Hetao Irrigation District based on water footprint[J]. Transactions of the Chinese Society for Agricultural Machinery, 2021,52(12):346 –357. (in Chinese).

[4] DENG LZ, YANG ZH, SU WC. Optimization countermeasures for crops planting structure in Karst area of Guizhou[J]. Economic Geography, 2017, 37(9):160 –166. (in Chinese).

[5] TAN Q, GOU TY, ZHANG TY, *et al.* A multi-objective robust programming model for agricultural water management with uncertain weights[J]. Journal of Hydraulic Engineering, 2020, 51(1):56 –68. (in Chinese).

[6] ZHANG XC. Research on crop water requirement and crop planting structure optimization in Kaidu-Kongque River Watershed[D]. Urumqi: Xinjiang University, 2019. (in Chinese).

[7] ROOSTAEE R, IZADIKHAH M, LOTFI FH. An interactive procedure to solve multi-objective decision-making problem: An improvement to STEM method[J]. Journal of Applied Mathematics, 2012, 2012:2607 –2645.

[8] National Agricultural Product Cost and Benefit Data Compilation[Z]. Beijing: China Statistics Press, 2019. (in Chinese).

[9] Statistics Bureau of Ningxia Hui Autonomous Region. Ningxia Statistical Yearbook[M]. Beijing: China Statistics Press, 2004 –2018. (in Chinese).

(From page 30)

regression coefficient of "whether to know the situation of land trusteeship" is positive and has passed the significance test of 5%, that is, compared with those who do not know land trusteeship, "knowing land trusteeship" will increase farmers' willingness to participate by 5.492 units. This shows that the provision of land trusteeship is in line with the needs of farmers for land management. In addition, determining whether farmers will eventually participate in land trusteeship is also highly related to farmers' expectations of land trusteeship, which indicates the possible development prospects of land trusteeship. This expectation is based on the comprehensive score of the current agricultural development, the impression of the trusteeship organization, the trusteeship operation system, and the reliability of the trusteeship effectiveness.

(iii) Government policy incentives and willingness to participate. Compared with the situation that if there is policy support, the farmers will wait and see to participate in land trusteeship, farmers who are willing to choose trusteeship if there is policy support will finally maintain the same willingness to choose land trusteeship, while farmers who are unwilling to choose land trusteeship if there is policy support will also maintain a higher consistency in the actual choice, that is, the relevant policies can encourage farmers to participate in land trusteeship.

4 Conclusion

Through the model analysis, three main factors affecting farmers' participation in land trusteeship and the related indicators are obtained. From the initial analysis framework and the final regression equation, the personal characteristics of farmers and the characteristics of their families do not have a dominant influence on their willingness to participate. In terms of agricultural operation, the specific variables that affect farmers' willingness to participate are the area of cultivated land, the type of planting, the number of types of agricultural machinery and the per unit yield of cultivated land. It is not difficult to see that behind these variables are farmers' consideration of their production input, efficiency and risk, that is, farmers' evaluation of their own agricultural operation has a great impact on their willingness to participate in land trusteeship. According to the survey data, only 57.1% of the sample farmers have heard of land trusteeship, and 61.4% of them are optimistic about the future development of land trusteeship. And these two factors significantly affect farmers' willingness to participate in land trusteeship, that is, farmers' cognitive guidance of land trusteeship needs to be paid attention to. In addition, the incentive effect of government policies can also induce a stronger will for land trusteeship. Based on the above analysis, it can be concluded that guiding farmers to strengthen their awareness of land trusteeship and introducing relevant policies that can provide great incentive to farmers can improve their willingness to participate in land trusteeship from the outside, that is, it can expand the demand of land trusteeship market and promote the development of land trusteeship. Through the analysis of the factors that affect farmers' willingness to participate in land trusteeship, it is also helpful for land trusteeship organizations to more accurately identify their potential customers, so that promoters can have rules to meet the needs of farmers.

References

[1] ZHANG X. Study on farmers' willingness to participate in land trusteeship in Shenyang[D]. Shenyang: Shenyang Agricultural University, 2018. (in Chinese).

[2] XIAO JY, ZHANG CL, CHEN LQ, *et al.* Investigation and demonstration of farmers' willingness to participate in land trusteeship[J]. Statistics & Decision, 2018,34(23): 113 –116. (in Chinese).

[3] HAN PP. Study on the demand behavior of land trusteeship of grain farmers and its influencing factors[D]. Jinan: Shandong University of Finance and Economics, 2019. (in Chinese).

[4] SUN XY, SU X. Land trusteeship, total income and willingness to grow grain: From the perspective of grain efficiency and income increase of part-time farmers[J]. Issues Agricultural Economy, 2012, 33(8): 102 –108, 112. (in Chinese).

[5] KONG XZ, ZHONG Z. Reform of supply and marketing cooperatives, land trusteeship and large-scale service: Investigation and reflection on the comprehensive reform of supply and marketing cooperatives in Shandong Province[J]. China Co-operative Economy, 2017(10): 36 –40. (in Chinese).

[6] ZENG QY, SUN K, TONG ZH. Comparative analysis of land transfer and land trusteeship from the perspective of farmers' choice[J]. World Agriculture, 2019(9): 4 –11. (in Chinese).

[7] HU LX, GU QK. Study on the coordinated development of land trusteeship and farmland income mortgage[J]. Rural Economy, 2019(12): 73 –80. (in Chinese).