The Research on Optimization of Agricultural Planting Structure in Minqin Basin under Water-saving Mode

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Abstract: Minqin Basin holds more rate of dependency on water resources and more vulnerability sensitivity to the ecological environment. It is the key to carry out research on the optimization of agricultural planting structure and priority research on water saving, so as to produce the largest economic and ecological benefits for agriculture under the condition of limited water resources. Research and study shall be carried out on the agricultural planting structure of Minqin Basin with examples through the establishment of constraints and objective functions and the construction of a linear programming model based on the high-efficiency water-saving technology of agriculture. The local crop planting structure has changed significantly from 1995 to 2020, which is mainly reflected in: (1) The total planted area of crops rose significantly, from 438,200 to 1000,000 hm^2; (2) The planting area of grain crops tends to grow, and the economic crops and other crops tend to fall down; (3) The local net output value rose up significantly, from 4.8 ×10^9 yuan in 1995 to 5×10^{10} yuan; (4)The planned crop planting area is slightly larger than the crop planting area in 2020. However, the total output value of crops grows to 3.43×10^8 yuan, which is 1.18 times the output value in 2020. As there are demands urgent for water saving in agricultural planting in Minqin, it is imperative to optimize planting structure and promote advanced irrigation technology.

Keywords: Agricultural Planting; Optimization Model; High-Efficiency Water-Saving; Structure; Minqin Basin

1. Introduction

There are three aspects for the sustainable development of agriculture that are society, economy and ecology, which is necessary to carry out maximum economic benefits under the premise of ensuring food security and ecological stability through reasonable planning to truly achieve a win-win performance for society, economy and ecology. As water conservancy is the lifeblood of agriculture, it is an inevitable choice to make efficient use of water resources for the sustainable development of agriculture in China [1], It is crucial to use water resources efficiently in order to promote agricultural sustainable development in China. Minqin Basin is located in the lower reaches of Shiyang River Drainage Basin. The water resources from Shiyang River Drainage Basin are the main water sources on the earth surface. Minqin Basin holds more rate of dependency on water resources and more vulnerability sensitivity to the ecological environment, both of which constitutes the biggest obstacle to the agricultural development of Minqin Basin (Figure.1). Minqin is a large-scale area for planting, where the water resources are mainly used for planting, which accounts more than 90% of the total water resources in the county, and planting is also the main source of economic income in Minqin, with planting income accounting for 69.41% of Gross National Product of the county. As the structure of planting industry is closely related to water resources, economic income and the ecological environment in Minqin Basin, the agricultural planting structure should be optimized to ensure a sustainable development of agriculture in the Minqin Basin and water - saving agriculture according to local conditions shall be developed to realize a coordination of agricultural development and environmental protection.

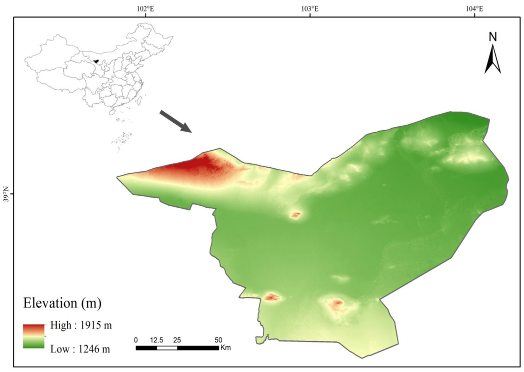

Figure 1. Map Showing the Location of Minqin Basin

2. Screening of Water-Saving Dominant Crop Varieties in Minqin Basin

2.1 The Current Status of Agricultural Planting Structure in Minqin Basin

In Minqin Basin, the grain crops mainly consists of wheat, corn, etc., economic crops are mainly for cotton, oil plants (mainly flax seeds), hemp, sunflower, fennel, pepper, onion and melons (mainly honey dew melon, seed melon), etc., pasture crop are mainly for alfalfa, etc. and natural vegetation includes sacsaoul, nitraria, artemisia sphaerocephala, rose willow, populus euphratica, achnatherum splendens and sarmi, etc. In recent years, high-water-consuming crops are vigorously compressed and water-saving crops are promoted and expanded in accordance with the idea of "Stabilizing Grain, Expanding Economic Growth, and Increasing Grass"[2-4].

2.2 Screening of Leading Crop Varieties

With consideration of the regional economic, social and ecological benefits goals, and combination of actual surveys with water resources, it fully takes in account the real problems of serious water shortages and the deterioration of the ecological environment in the selection of leading crop varieties, and then screen out the dominant crop varieties through calculation, analysis and evaluation on the water production efficiency of crops. The calculated water use efficiency for each kind of crop (Figure 2,Figure 3,Figure 4). With the basis of the above, the planting area of 10 crops is selected as the decision variables, including 2 grain crops, such as spring wheat and corn; 7 cash crops, such as oil sunflower, fresh sunflower, pepper, cotton, onion, melon, fennel; 1 forage, namely alfalfa.

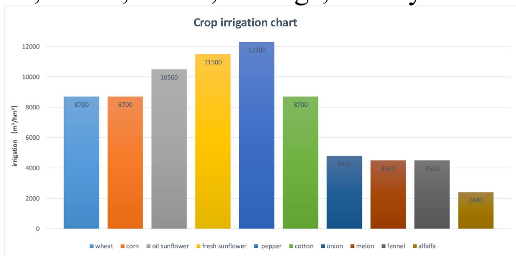

Figure 2. Production Benefits of Crop to Water

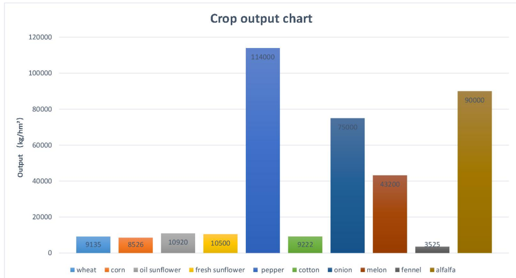

Figure 3. Production Benefits of Crop to Water

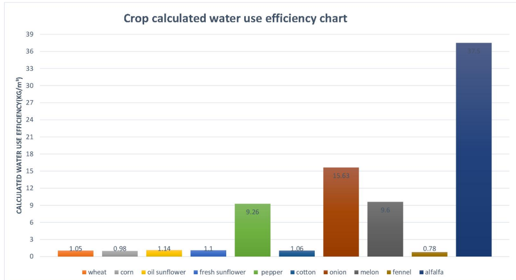

Figure 4. Production Benefits of Crop to Water

From the perspective of economic benefits: Pepper is in the highest economic benefit, with an output value of more than 100,000 yuan per hectare, and the lowest economic benefits is for traditional crops such as spring wheat and fennel, with output values of only 9,135 yuan and 3,525 yuan respectively. the analysis water use efficiency: alfalfa, onion and pepper are most efficient, respectively at 37.50 kg/m³, 15.63 kg/m³ and 9.26kg/m³, of which the water use efficiency of fennel and corn is lowest, only for 0.78 kg/m³ and 0.98kg/m³. With combination and consideration of the current situation of resource shortage and water resources carrying capacity in Minqin Basin, priority shall be given to crop varieties with high water use efficiency when planting structure is adjusted, and the planting area of crops with high water consumption and low benefit shall be tried to be minimized [5].

3. Research Methods

3.1 Design of Optimization Decision Mathematical Model

Considering the practicality of production, the research was carried out on the agricultural planting structure through a linear programming model. The mathematical model consists of two parts: constraint conditions and objective function [6].

Objective function: It takes the maximum economic benefit of the system as the optimization goal in the model.

Constraint conditions: It reflects the restrictions from resources on production activities, social demands, internal objective laws of agricultural production, and socioeconomic conditions, etc. The constraint conditions involved in the study are:

(1) The constraint on total amount of agricultural production, requiring that the total output of the main products produced in the planting industry should meet the annual regional per capita occupancy target and the national plan target on the planned level;

(2) The constraint from aquaculture industry on the demand for agricultural and sideline products, requiring to satisfy the constraints on the demand for agricultural and sideline products by planting, raising, and processing (processing of agricultural and sideline products);

(3) The constraint on land area, requiring that the total land area for regional development should be less than the total area of arable land in the area;

(4) The constraint on water resource, requiring that the amount of available water resources should be equal or greater than the total planned annual water demand;

(5) The constraint on water supply capacity, requiring that the water demand during the period should be less than or equal to the channel's water passing capacity or the electromechanical well water lifting capacity;

(6) The constraint on labor resource, requiring that the total labor for farming in the season of crop production should be less than or equal to the total labor that can be provided;

(7) The constraint on policy, requiring, for example, per capita food targets, residents living standards shall meet the annual requirement on planning level, etc.

3.2 Decision Variables

Taking the planting area F_{ij} of various crops as the decision variable (hm^2), the subscript i refers to the crop number (i=1,2,3,…,m) ,respectively refers to spring wheat, corn, oil sunflower, fresh sunflower, pepper, cotton, onion, melon, fennel, alfalfa, etc; the subscript j refers to number.(j=1,2,……,n) The planting area of 10 crops is selected as the decision variables, including 2 grain crops, such as spring wheat and corn; 7 cash crops, such as oil sunflower, fresh sunflower, pepper, cotton, onion, melon, fennel; 1 forage, namely alfalfa.

3.3 Constraint Equation

(1) Constraints on Grain Production

$$\sum_{j=1}^{n}\sum_{i=1}^{2} M_{ij} gF_{ij} \geq R_f \tag{1}$$

The formula, M_{ij} refers to the per unit area yield of various types of grain crops in different subregions (kg/hm^2), and R_f refers to the total grain demand target(kg).

(2) Constraints on Agricultural and Sideline Products

$$\sum_{i=1}^{10}\sum_{j=1}^{n} B_{ij} gF_{ij} = R_B \tag{2}$$

In the formula, B_{ij} refers to the per unit area yield of agricultural and sideline products that different crops can provide(kg/hm^2); R_B refers to the index of demand for agricultural and sideline products in the farming and processing industry (kg). Considering the demands in the development of the aquaculture industry, the agricultural and sideline products that can be provided by various crops should meet the demand in the development of the aquaculture industry.

(3) Constraints on Oil Sunflower Planting

$$\sum_{j=1}^{n} F_{3j} = M_{f3} \tag{3}$$

In the formula, M_{f3} refers to the area index of oil sunflower planting required by the national plan (hm^2).

(4) Constraints on Planting Area of Fresh Sunflower

$$\sum_{j=1}^{n} F_{4j} = M_{f4} \quad (4)$$

In the formula, M_{f4} refers to the current planting area of fresh sunflower (hm^2).

(5) Constraints on Planting Area of pepper

$$\sum_{j=1}^{n} F_{5j} = M_{f5} \quad (5)$$

In the formula,M_{f5} refers to the current planting area of pepper (hm^2).

(6) Constraints on Planting Area of cotton

$$\sum_{j=1}^{n} F_{6j} = M_{f6} \quad (6)$$

In the formula, M_{f6} refers to the current planting area of cotton (hm^2).

(7) Constraints on Planting Area of onion

$$\sum_{j=1}^{n} F_{7j} = M_{f7} \quad (7)$$

In the formula, M_{f7} refers to the current planting area of onion (hm^2).

(8) Constraints on Planting Area of melon

$$\sum_{j=1}^{n} F_{8j} = M_{f8} \quad (8)$$

In the formula, M_{f8} refers to the current planting area of melon (hm^2).

(9) Constraints on Planting Area of fennel

$$\sum_{j=1}^{n} F_{9j} = M_{f9} \quad (9)$$

In the formula, M_{f9} refers to the current planting area of fennel (hm^2).

(10) Constraints on Planting Area of alfalfa

$$\sum_{j=1}^{n} F_{10j} = M_{f10} \quad (10)$$

In the formula, M_{f10} refers to the current planting area of alfalfa (hm^2).

(11) Constraints on Multiple Index

$$\frac{1}{AL}\sum_{i=1}^{10}\sum_{j=1}^{n} F_{ij} \leq E \quad (11)$$

In the formula, E is the design multiple cropping index, which is set at 1.75 in this paper; AL is the existing agricultural acreage (hm^2).

(12) Constraints on Land Resource

The total of various simultaneous planting areas is not more than the total cultivated area.

$$\begin{cases} \sum_{i=1}^{10}\sum_{j=1}^{n} F_{ij} \leq PAL \left(i \neq 2, 3, 4, 6, 8, 10\right) \\ \sum_{i=1}^{10}\sum_{j=1}^{n} F_{ij} \leq PAL \left(i \neq 1, 5, 7, 9\right) \end{cases} \quad (12)$$

In the formula, PAL is the planned arable land area (hm^2).

(13) Constraints on Water Supply Capacity

$$\sum_{i=1}^{10}\sum_{j=1}^{n} W_{ijk} g F_{ij} \leq Q_k \quad (13)$$

In the formula, Wijk is the irrigated water volume of different crops in different divisions in each irrigation period(m^3/hm^3), and Qk is the water supply capacity of the project in the corresponding period (m^3).

(14) Constraints on Total Water Resource

$$\sum_{k=1}^{n} Q_k \leq WR \quad (14)$$

The massive consumption of water resources will inevitably cause great resistance to the healthy development of the regional economy in the Minqin Basin, where water resources are in serious shortage. Water resource constraints are the most powerful in optimizing the regional planting industry structure. The irrigation volume of all planted crops should not exceed the amount of irrigation water that the Minqin Basin can provide,Hence, It is crucial consider the water resource constraints(m^3)[7,8].

In the formula, WR is the total volume of local available water resources,

(15) Constraints on Labor Resource

$$\sum_{i=1}^{10}\sum_{j=1}^{n} L_{ij} F_{ij} \leq L_t \quad (15)$$

In the formula, Lij is the amount of labor used per unit of cultivated area; Lt is the maximum labor resource that can be provided.

(16) Non-negative Constraints

The variables are non-negative.

3.4 Objective Function

Objective Function 1: To maximize the comprehensive net economic benefit of growing crops.

$$MaxB(\mathrm{F}) = \sum_{i=1}^{10}\sum_{j=1}^{n} P_j g y_{ij} g F_{ij} - \sum_{i=1}^{10}\sum_{j=1}^{n} C_{ij} g F_{ij} \quad (16)$$

In the formula, P_j is the comprehensive sales price of the products (including by-products) of the planted crops (yuan/kg); y_{ij} is the per unit area yield of the class-i crop (including by-products) in zone j (kg/hm^2); C_{ij} is the unit production and unit cost of the class-i crop in zone j (yuan/hm^2), B (F) is the total net benefit of production (yuan)[9].

Objective Function 2: Output Function. That is, the planted crops with highest yield.

$$\max f_2(A_1, A_2, \cdots A_{12}) = \sum_{i=1}^{10} A_i \times S_i \quad (17)$$

In this formula: S_i The yield of the class-i crop under irrigation conditions (kg/hm2);

Objective Function 3: Ecological benefit function. It refers to the ecological benefits which results from the adjustment of agricultural planting structure, excluding the ecological benefits of rivers, lakes, ponds, and wetlands[10].

$$\max f_3(A_1, A_2, \cdots A_n) = \sum_{i=1}^{10} A_i \times ECO_i \quad (18)$$

In the formula: ECO_i is expressed as the contribution rate of the unit area to the ecology when the class-i crop is irrigated.

4. The Research on Optimization of Agricultural Planting Structure in Minqin

The planting area of the above-mentioned ten main crops was used as the decision variables, taking the Minqin Basin in the Shiyang River Basin as the research area(hm^2), namely: spring wheat (A_1), corn (A_2), oil sunflower (A_3), fresh sunflower (A_4), pepper (A_5), cotton (A_6), onion (A_7), melon (A_8), fennel (A_9) and alfalfa (A_{10}). The corresponding net output value per crop area is referred as: spring wheat (P_1), corn (P_2), oil sunflower (P_3), fresh sunflower (P_4), pepper (P_5), cotton (P_6), onion (P_7), melon (P_8), fennel (P_9), alfalfa (P_{10}).

The target to optimize and adjust the crop planting structure is to maximize the total output value y (yuan), according to the formula (16)—(18). Therefore, the objective equation is:

$$Y_{\max} = A_1P_1 + A_2P_2 + A_3P_3 + A_4P_4 + A_5P_5 + A_6P_6 + A_7P_7 + A_8P_8 + A_9P_9 + A_{10}P_{10} \quad (19)$$

The conditions are required as the following according to the constraint equation (1)—(15):

(1) The planting area of the main crops is constrained by the total irrigation area, and the irrigation area is 1000 ,000 hm^2 in 2020, therefore:

$$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} \le 1000000 \quad (20)$$

(2) As the local is irrigated agriculture, different crop types with different irrigation water requirements, such as water demand for spring wheat and corn irrigation is 8700 m^3 /hm^2, pepper is maximum 12300 m^3 /hm^2, alfalfa irrigation water demand is minimum 2400m^3 /hm^2. However, the total water supply is determined by the waterworks department in accordance to the research of the area of the Minqin that, the water supply per unit area is 8535 m^3 /hm^2. Therefore, the water consumption for irrigation is constrained by the total water supply (The agricultural irrigation in Minqin Basin is still dominated by conventional irrigation, so it can be assumed that the local coverage of water-saving technology is still low for a few years, and it will not be considered) (The water demands are all fixed in Doukou modular system).

$$8700A_1 + 8700A_2 + 10500A_3 + 11500A_4 + 12300A_5 + 8700A_6 + 4800A_7 + 4500A_8 + 4500A_9 + 2400A_{10} \le 8535(A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10}) \quad (21)$$

According to existing research, the consumption of fine grains has long dominated in the grain consumption of rural residents in China, and coarse grains such as corn are no longer daily rations in people's life. Wheat is the main ration and rice consumption is less than 10% in the typical northern region of China. What's more, rice is rarely cultivated in Hexi regions, mainly for outsourcing, therefore, only wheat is considered in grain consumption. The grain security line is 400 kg/person·a in China, and the direct consumption of fine grain by rural residents is 189.8 kg/person. Therefore, 200kg / person can basically meet the basic demand for rations, combined with the actual situation in Gansu and existing research. The agricultural population is 179,300 in Minqin in 2020. The average yield of wheat is 7275 kg/hm^2 from 1995 to 2020. Therefore, the total output of rations should not be less than the basic demands from local farmers:

$$7275A_1 \ge 179300 \times 200$$

That is:

$$7275A_1 \ge 35860000 \quad (22)$$

(4) As a grain crop, only a small part of corn is used for rations, which is mainly for feed

grains. The per capita grain consumption demand is about 350 kg in 2020 in China, according to existing research, and the average corn yield is 11,509 kg /hm^2. Therefore, the total grain output should not be less than the basic needs of local farmers:

(5) The unilateral net water output value of different crops (yuan / ton)) is calculated (The high net output value of unilateral water indicates that the value created by unit water is high, that is, such crops are easier to grow in water-scarce areas), according to the net output value and crop water quota of different crops provided by the field survey of the research area, Gansu Provincial Economic Crops Technology Extension Station and Gansu Rural Collective Financial and Asset Supervision and Management Station.

The unilateral aquatic product value of cotton, melon, onion and other is relatively large according to the calculation of unilateral aquatic product value(>3), the unilateral aquatic product value of wheat, corn, sunflower, oil sunflower is relatively small (<3), so the planting area of crops with small unilateral aquatic product value should be appropriately reduced, the planting area of crops with large unilateral aquatic product value shall be expanded, however, as wheat and corn are grain crops, the size of the planting area directly affects local food security and social stability, so the unilateral aquatic product value is not considered here for constraints on wheat and corn, so as to get the following formula:

$$A_3 \geq 1.7 \tag{23}$$

$$A_4 \geq 4 \tag{24}$$

$$A_5 \leq 2.75 \tag{25}$$

$$A_6 \geq 27.37 \tag{26}$$

$$A_7 \leq 3.85 \tag{27}$$

$$A_8 \leq 10.2 \tag{28}$$

$$A_9 \leq 2.83 \tag{29}$$

$$A_{10} \leq 1.3 \tag{30}$$

5. Discussion

The local planting structure changes have been obtained according to the statistical analysis of the crop planting area data obtained from the 1995-2020 statistical yearbook of the townships and farms that Minqin belongs to; Table 1 is worked out after the local planting structure adjustment plan is solved according to the linear programming model constructed above (Figure5).

Table 1. The Table of Planting Structure that Minqin Has Carried out and Need to Adjust Unit: 10,000 hm2

Crop type	1995		2020		After adjustment	
	Crop area	proportion	Crop area	proportion	Crop area	proportion
Wheat	20	45.64	35	35	35	35
corn	6.04	13.78	11	11	11	11
oil sunflower	1.0	2.28	1.7	1.7	5	5
fresh sunflower	3.88	8.85	4	4	6	6
Pepper	0.88	2.01	2.75	2.75	5	5
Cotton	5.79	13.21	27.37	27.37	21.5	21.5
Onion	1.06	2.42	3.85	3.85	3.5	3.5
Melon	2.2	5.02	10.2	10.2	10	10
Fennel	1.04	2.37	2.83	2.83	2	2
Alfalfa	0.23	0.52	1.3	1.3	1	1
total	43.82	100	100	100	100	100

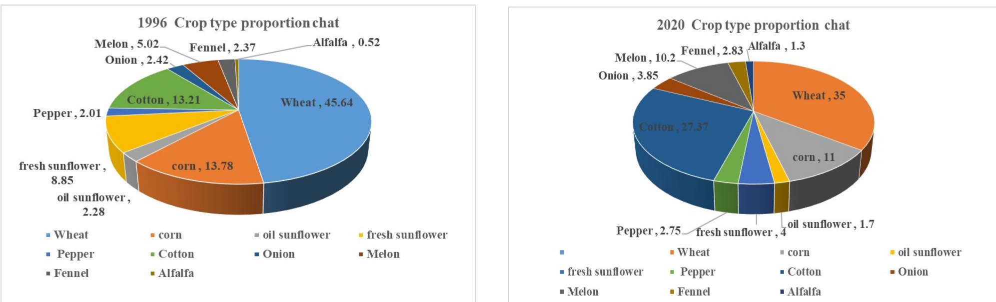

Figure 5. Crop Type Proportion Chart

5.1 Adjustment of Planting Structure

The local crop planting structure has changed significantly from 1995 to 2020, which is mainly reflected in:

(1) The total planted area of crops rose significantly, from 438,200 hm^2 to 1000,000 hm^2;

(2) The planting area of grain crops tends to grow, and the economic crops and other crops tend to fall down, among which, the planting area of grain crops went up from 26.04% in 1995 to 46% in 2020, and economic crops went down from 73.96% in 1995 to 54% in 2020;

(3) The local net output value rose up significantly, from 4.8×10^9 yuan in 1995 to 5×10^{10} yuan . The agricultural output value has been greatly improved although through the adjustment of planting structure in the past 20 years. For example, the area of economic crops is reduced under the premise of ensuring the self-sufficiency of local farmers, and the reduced cultivated land is used to increase the cultivation of grain crops, among which, the net water output value of cotton and melons is higher than other types of crops. Therefore, the planting area of melons and cotton has greatly grown in the past 20 years, but the above adjustments are only driven by farmers and local governments due to economic interests and other factors. The adjustments made are lacking in a unified plan for coordinated social-economic-environmental development.

5.2 The Planning for the Adjustment of Planting Structure

For example, it can properly plan the local crop planting structure with the use of multiple linear programming methods, so as to maximize economic benefits without negatively affecting the local society and ecological environment. The planned crop planting area is slightly larger than the crop planting area in 2020. However, the total output value of crops grows to 3.43×10^8 yuan, which is 1.18 times the output value in 2020. The specific adjustment plan is as follows:

(1) The planting area of wheat, corn and melon is basically not changed. The proportion has not changed.

(2) The planting area of oil sunflower, fresh sunflower and pepper is increased. Among them, oil sunflower grew from 17,000 hm^2 to 50,000 hm^2 and only went up by 33,000 hm^2 to 5%; fresh sunflower rose from 40,000 hm^2 to 60,000$hm^2$and increased by 20,000hm^2 to 6%;

(3) The planting area of cotton, onion, fennel, alfalfa and other crops fell down. Among them, cotton was adjusted from 27.37% to 21.7%, and the planting area was reduced to 217,000 hm^2 ; onions were adjusted from 3.85% to 3.5%, and the planting area was reduced to 35,000 hm^2; fennel was adjusted from 2.83% to 2% and the planting area was reduced to 20,000 hm^2; The alfalfa was adjusted from 1.3% to 1%, and the planting area was reduced to 10,000hm^2.

6. Conclusion

(1) The economic benefits are maximized by optimizing the planting structure reasonably under the premise of ensuring grain security and ecological stability, in order to truly achieve a win-win situation society, economy and ecology situation. Over the past 30 years, the adjustment of planting structure in Minqin along Shiyang River has achieved performance in creating agricultural economic benefits under the impetus of market economy. The area of food crops planted should be expanded to ensure food security at present, and cotton with high net output value in unit unilateral water should be planted more; The agriculture is developing towards the route of large-scale planning, intensive and characteristic management at present in China, and small-scale and decentralized management methods can no longer meet the current development needs. Therefore, some scattered cultivation crop area in small scale should be reduced.

(2) The demand for water saving in agricultural planting is urgent and imperative in Minqin. As one of the most water-scarce countries in the world, Israel is with a per capita water resource of only 325m^3, and the per capita water resources in Minqin County is 1.6 times that of Israel. However, the backward irrigation technology and water efficiency are far behind Israel. The contradiction between resource supply and demand is more prominent than Israel. Therefore, Minqin must require the implementation of water-saving agriculture, to achieve the purpose of maximum saving of

irrigation water through different measures, improve the reuse rate of water resources, so that it can produce the greatest economic and ecological benefits with limited water resources. Efficient water-saving technology is the main way to solve the problem of water shortage and also the prerequisite for the development in Minqin Basin.

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