Research on Irrigation System of Limited Water Supply for Soybean Crops in Shanxi Province

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Abstract. The limited water supply irrigation system for soybean crops in Shanxi Province was studied. The irrigation data of Limin experimental station in Linfen City, Shanxi Province had been selected. Frequency calculation of rainfall data of Limin was made, choosing 2010, 1993 and 1997 respectively as the sample year of plain water year (50%), water year dry year (75%) and special drought year (95%) of Limin. The Jensen model as the basis for calculation was selected, calculating the actual yield value of crop according to the actual crop water requirement, crop maximum water demand, sensitive index value and maximum crop yield at each stage. Through the selection of the number of days of irrigation, the optimization model of irrigation times was established. The limiting condition is the maximum actual yield. The quota irrigation system of soybean crops in different hydrological years was determined. According to calculation results, each target year was three times, with the highest amount of water.

Keywords: Irrigation system · Quota water supply · Shanxi Province Soybean crops

1 Introduction

With the continuous progress of human society, the level of scientific and technological production continues to develop, our demand for water is increasing and the range of use will become more and more extensive. Agricultural irrigation is no longer simple irrigation of crops, and how to carry out effective and reasonable scientific irrigation has become the consensus of people. Under the premise of the serious shortage of water resources, agricultural irrigation is difficult to make adequate supply of water needed for every stages of crops growthy, so the optimal utilization of irrigation water resources becomes more and more important. In the case of water shortages and insufficient water supply, the irrigation water is optimized at different stages of the crop to optimize the irrigation allocation, so as to obtain higher irrigation benefits and achieve the goal of increasing production in this way.

Published by Springer Nature Switzerland AG 2019
D. Li and C. Zhao (Eds.): CCTA 2017, IFIP AICT 546, pp. 263–270, 2019.
https://doi.org/10.1007/978-3-030-06179-1_27

Linear programming, referred to as LP [1, 2], helps us to study linear constraints, as well as to understand some of the related objective functions. XiaoSujun et al. [3–5] started from the actual water sensitivity index and the water production function of a part of irrigation areas in the Yellow River. They pointed out the main irrigation time of all kinds of crops and Got the irrigation system under the condition of quota of water supply in irrigated area. Qiu Lin et al. [6–8] gave the irrigation system with a multi-level innovation model that contains the risk index of crop planting which not only reduces the risk of planting, but also reduces the amount of water used for irrigation. Based on the viewpoint of non sufficient irrigation, Wang Zhiliang et al. [9–11] provided a irrigation system suitable for single crop in irrigation area and a dynamic programming model. They set up models to analyze the combined use of various water resources, and in the model to reflect the first use of surface water facts. According to the advantages of the accelerated genetic algorithm (RAGA) and the multidimensional dynamic programming (DP) method, the genetic dynamic programming model (RA GA DP) was given by Fu Qiang et al. [12, 13], which is helpful to eliminate the premature precocity in the improvement of irrigation system, and to emphasize local optimization and not easy to get the most suitable. CuiYuanlai [14, 15] had analyzed the actual water production function of the crops and concluded that the net irrigation of crops during different growth periods was best suited to the deployment by means of SDP, getting an effective irrigation system for a single crop.

We should provide adequate water supply during the growth period where the crops need water for the most part. The specific time of yield increase is given when the irrigation critical water is obtained, and the crop yield under different irrigation levels is estimated in every target years of water. Determine how much water is used to determine yield, and then to optimize the irrigation system of crops. To promote the limited water resources to the maximum benefit in order to achieve the goal of water-saving irrigation. According to the different factors of different crops, we have made a suitable irrigation system, which has a remarkable effect on agricultural water saving. Therefore, it is significant to study the irrigation system of crop quota water supply.

2 Materials and Methods

2.1 Selection of Soybean Experiment

Through the experiment data of soybean in Shanxi province, the main experimental sites of soybean crops were distributed in the Hutuo River, Central Experimental Station, Wenyuhe, Licheng, Linfen, Huoquan and Limin. This study choosed the data of the Limin experimental station in the Linfen city of Shanxi Province to study the quota irrigation system.

2.2 Test Processing Design

According to the situation of rainfall and crop water requirement in the Limin test station in Shanxi Province, five treatments were designed according to the plan of the provincial hall. The area area was 34.8 m^2.

2.3 Field Operation Management

Using the local field cultivation and management measures, tested varieties was Fen bean 17, sowing rate was 10 kg/mu, it was fertilizers applied Yunnan phosphate fertilizer of 40 kg/mu. During intertill 3 times, the depth was 5 to 7 cm.

2.4 Meteorological Conditions of Soybean

The average temperature of soybean was 20.6° in growth period; the total rainfall was 216.4 mm, effective rainfall was 201.5 mm; belonging to plain water year, water surface evaporation (20 cm diameter) was 549 mm; sunshine hours was 500.1 h; the relative humidity was 76%; natural disasters did not occur.

2.5 Soil Moisture Determination

Soil moisture was determined by soil drilling and soil drying method. The soil depth was 140 cm, (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, 80–100 cm, 100–120 cm, 120–140 cm), which was measured in seven layers. Soil moisture was measured every ten days during the growth period of soybean: on the 1st, 11th and 21st days of each month at the beginning of the growth stage and after precipitation.

2.6 Irrigation Situation

In the test, the water well irrigation, water meter measurement water quantity and the field irrigation water delivery system were adopted. The semi fixed plastic pipeline was used to transport water, and the water outlet pipe was connected with the hose for irrigation.

2.7 Field Observation Survey

At the growth stage of soybean, plant growth was observed, and yield structure were determined after harvest.

2.8 Basic Parameters

According to historical data, the soybean irrigation quota was 50 mm. In recent years, the maximum yield per mu of soybeans was 175 kg/mu. The soil basic parameters, soybean stages, crop coefficients and soybean growth period are shown in Tables 1 and 2.

Table 1. Soil basic parameters of test station

Area	Volume weight of soil (g/m^3)	Soil depth (m)	Field moisture capacity (percent by weight)	Wilting percentage (percent by weight)	Initial rate of water content
Limin	1.46	0.5	24.6	6	19.2

Table 2. Observation record of soybean growth period

Area	Year	Sow	Branch	Bloom	Pod	Seed-filling	Harvest
Limin	2008	5.19	7.2	7.12	7.22	8.12	9.12

3 Formulation of Soybean Quota Irrigation System

3.1 Frequency Calculation

Irrigation design reliability is that the probability of irrigation water consumption can be fully satisfied over the years in the irrigation area, generally expressed by the percentage of years which design irrigation water is fully satisfied in total computed years. Formula see form (1).

$$P = \frac{m}{n+1} \times 100\% \tag{1}$$

Formula: P is the guarantee rate of irrigation design; m is to calculate the number of years when the water supply is greater than or equal to the irrigation water requirement; n is the total number of years for the calculation series, in large and medium-sized irrigation areas, the calendar year should not be less than 30 years.

Based on the analysis of precipitation frequency table in Linfen city of Shanxi Province, the meteorological data of three typical hydrological years in 2010 (50%), 1993 (75%) and 1997 (95%) were selected as the basis for the study of the quota irrigation system.

3.2 Calculation of Crop Water Requirement

In the study, the method of calculating the actual crop water requirement was adopted by reference to the water requirement.

Crop coefficient KcCrop coefficient can be divided into four stages: initial growth stage, rapid growth stage, middle fertility stage and mature stage. By referring to the crop coefficient recommended by FAO, the coefficient of soybean crop in Limin area is shown in Table 3.

Table 3. Coefficient of soybean fractional crop

Area	Growth stage	Initial growth stage	Rapid growth stage	Medium maturity stage	Full growth stage	Whole growth period
Limin	Crop coefficient	0.67	0.67–1.09	1.09	1.09–0.48	
	Days	20	30	40	27	117

Soil moisture correction coefficient. The model proposed by Lei Zhidong et al. (1988), see form (2).

$$K_s = \begin{cases} 1 & \theta \geq \theta_j \\ a + b\theta & \theta \leq \theta_j \\ 0 & \theta \leq \theta_{wp} \end{cases} \tag{2}$$

θ is the actual water content of soil root layer; θ_{wp} is permanent wilting point moisture content. θ_j is critical moisture content

Actual crop evapotranspiration. Meteorological factors, crop factors and soil factors should be taken into consideration in actual crop water requirements. Its formula is formula 3.

$$ET = K_s K_c ET_0 \tag{3}$$

In the formula, ET is the actual crop evapotranspiration; ET0 is the reference crop evapotranspiration; Kc is the crop coefficient; Ks is the soil water correction coefficient.

3.3 Determination of Crop Water Production Function

Crop water production function is a mathematical model which reflects the variation of crop yield and water content, and is the basic theoretical basis for irrigation planning, design and management of non sufficient irrigation. Jensen model is a static model of water production function, referred to as the multiplicative model, widely used in recent years. The expressions for the Jensen model are present in Eq. (4).

$$\frac{y}{y_m} = \prod_{i=1}^{n} \left(\frac{ET}{ET_{mi}} \right) {}^{\lambda_i}_{i} \tag{4}$$

In formula: n is the number of stages of crop fertility; i is the number of the crop stages; Y is the actual yield of crops (kg/hm^2); Ym is the maximum yield (kg/hm^2) for full irrigation. ETi is the actual evapotranspiration in i growth stage (mm); ETmi and Ym corresponding to the i evapotranspiration growth stage (mm); λi is a sensitive index in lambda i growth stage, reflecting the influence on output stage water shortage degree, and it is an important parameter in the model.

Selection of sensitivity index. According to the experimental data of Jensen model, the sensitive index of the growth stages of soybean crops was calculated, shown in Table 4.

Table 4. Sensitive index tables of different growth stages of soybean

Area	Year	Growth period	Sowing branching	Branches-flowering	Flowering-podding	Podding-Seed-filling	Seed-filling-mature
Limin	2009	Sensitivity index	0.0182	0.2527	0.1621	0.3292	0.2277
		Cumulative days	5	33	43	64	114

Calculation of water production function at each growth stage. Equation (3) shows that:

$$\frac{y}{y_m} = \left(\frac{ET}{ET_{m1}}\right)^{\lambda 1} \times \left(\frac{ET}{ET_{m2}}\right)^{\lambda 2} \times \cdots \times \left(\frac{ET}{ET_{mn}}\right)^{\lambda n}$$

$$y = \left(\frac{ET}{ET_{m1}}\right)^{\lambda 1} \times \left(\frac{ET}{ET_{m2}}\right)^{\lambda 2} \times \cdots \times \left(\frac{ET}{ET_{mn}}\right)^{\lambda n} \times y_m \tag{5}$$

Through the formula 5, the actual crop yield Y can be obtained according to the actual crop water requirement, crop maximum water demand, sensitive index value and maximum crop yield at each stage.

According to the sensitivity index, the actual water requirement, the maximum water requirement at each stage and the water production function value of the 5 growing stages was calculated.

3.4 Determination of Irrigation Time

According to the research of irrigation on soybean irrigation system, the irrigation times were determined up to 3 times. So the limited irrigation system has three kinds of circumstances, choosing once, twice and three times watering in each plain water year, as the limit conditions was the actual maximum yield.

The pattern search method is adopted in this research to derive the maximum yield of crops. In the process of probing derive, according to the coordinate direction, the values are searched at a certain step size, when exploration results failed, step length is shrinked and searched again, until the search step length is less than the given accuracy.

According to the above calculation process, the limited water supply irrigation system for soybean crops has been worked out in different hydrological years, as shown in Table 5.

Table 5. Soybean limited irrigation system

Hydrological year type	Irrigation frequency	Irrigation quota	Irrigation time	ET_m (mm)	ET_0 (mm)	P (mm)	(kg/mu)
50% (2010)	1	50	36	372.11	416.12	246.3	114.41
	2		30/36				141.43
	3		10/30/36				161.55
75% (1993)	1		33	392.06	444.22	262.2	133.71
	2		16/33				159.05
	3		1/16/33				170.80
95% (1997)	1		31	494.26	552.82	167.5	107.11
	2		22/31				128.49
	3		22/31/52				141.95

4 Conclusion

This study selected the irrigation data of Limin experimental station in Linfen city of Shanxi province, the irrigation system of limited water supply for soybean crops were studied in Shanxi province. Rainfall data were calculated at choosing 2010, 1993 and 1997 respectively as the sample year of plain water year (50%), water year dry year (75%) and special drought year (95%) of Limin. The Jensen model were selected as the basis for calculation, calculating the actual yield value of crop according to the actual crop water requirement, crop maximum water demand, sensitive index value and maximum crop yield at each stage. Through the selection of the number of days of irrigation, the optimization model of irrigation times were established. Every kinds of target years of water was respectively chosen to fill the water once, two times, and three times. The limiting condition is the maximum actual yield. The quota irrigation system of soybean crops in different hydrological years in Limin area was determined. According to calculation results, each target year was three times, with the highest amount of water. In actual irrigation, water shortage is often encountered and irrigation is required according to the limited water supply system. Therefore, it is necessary to analyze the irrigation system with limited water supply. The calculation results can provide the basis for the establishment of irrigation system for local crops.

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