RESEARCH ON ECOLOGICAL AGRICULTURE IRRIGATION TECHNOLOGY IN ARID AREAS BASED ON WATER FERTILIZER COUPLING MODEL: TAKING SUGAR BEET CULTIVATION AS AN EXAMPLE

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(Received 9th Nov 2023; accepted 19th Jan 2024)

Abstract. The aim of this study is exploring the development strategies of ecological agriculture in arid areas through the issue of beet irrigation. Based on the quadratic regression rotation method, a water fertilizer coupling model for film-based sugar beet irrigation was established, reflecting the effects of irrigation water volume, nitrogen fertilizer application amount, and potassium fertilizer application amount on sugar beet yield, and considering the interaction of three factors. The experimental results of 20 experimental fields in Ningxia region, China showed that the three factors affecting sugar beet yield from strong to weak were nitrogen fertilizer application amount, irrigation water amount, and potassium fertilizer application amount. Moreover, there was a strong interaction between irrigation water amount and nitrogen fertilizer application amount on sugar beet yield. Furthermore, based on the results irrigation strategies for sugar beets in arid areas can be provided: during the high-water period, the amount of irrigation water should be appropriately increased and the amount of nitrogen fertilizer applied should be reduced; During the dry season, the amount of irrigation water should be appropriately reduced and the amount of nitrogen fertilizer applied should be increased.
Keywords: *ecological agriculture, arid areas, irrigation water quantity, fertilization amount, secondary rotation, single factor analysis, cross factor analysis, sugar beets*

Introduction

Ecological agriculture places special emphasis on the coordination of economy, environment, and agricultural production, with respect to the natural environment as a prerequisite. On the basis of fully considering the natural environment, achieving sustainable development of agricultural production is an important feature of ecological agriculture (Chatterjee et al., 2022; Forestal et al., 2021; Egya, 2021; Dinesh et al., 2022). Ningxia is a province in northern China, and drought is an important feature of its natural environment. To achieve sustainable development of ecological agriculture in terms of drought environment, it is necessary to comprehensively consider and coordinate the use of irrigation and fertilization (Patra et al., 2022; Hao, 2022).

Although the absorption of water and nutrients by crop roots is two independent processes, their effects on crop growth are interdependent. Studying the interaction effect between water and fertilizer, clarifying the water and fertilizer consumption and demand patterns of crops, can provide guidance for actual production, and is also an important strategy for solving irrigation schemes in arid areas (Stevens et al., 2006; Zhang and Shao, 2021; Li et al., 2023). In actual production, many farmers have increased crop yields by applying large amounts of fertilizers, uncontrolled irrigation, and spraying pesticides. However, the fact has been proven that this approach is

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_16831695

unreasonable, as it not only increases cost input, but also leads to water and fertilizer waste and eutrophication of water bodies. So, only by systematically managing irrigation and fertilization can we improve yield, water and fertilizer utilization efficiency (Ierna et al., 2011; Alves et al., 2023; Singh et al., 2022).

The coupling technology of water and fertilizer comes from the integration technology of water and fertilizer. The integrated technology of water and fertilizer, also known as micro irrigation fertilization technology, can optimize the combination of water and fertilizer to supply crops. It utilizes a pressure system or natural drop to combine micro irrigation with fertilization, applying fertilizer to the crop roots while irrigating (Guo et al., 2023; Dai et al., 2021). The integrated technology of water and fertilizer has the advantages of water-saving potentials, improving fertilizer utilization efficiency, reducing pesticide use, increasing crop yield, improving soil microenvironment, and saving labor in irrigation and fertilization management. The main characteristics of irrigation and fertilization techniques under drip irrigation conditions are: low flow rate, long duration, high frequency, local irrigation, and on-demand distribution (Singh et al., 2021).

Scholars' research on the coupling effect of water and fertilizer is not limited to field crops, but also has corresponding research on economic crops. Karunakaran et al. (2021) found that under various fertilizer ratios, the yield of fruit cucumber showed a trend of first increasing and then decreasing with the increase of irrigation amount during the growth period. Aluoch et al. (2022) found that under drip irrigation fertilization conditions, different water and fertilizer factors all exhibit a positive interaction on yield, and the interaction between fertilizer and water factors is greater than that between fertilizer factors. Carver et al. (2022) found that under the condition of drip irrigation under film, the relationship between the yield increase effects of various factors in dryland rice is: irrigation quota > nitrogen application rate > phosphorus application rate. Amjad et al. (2021) found that water nitrogen interaction has a gain effect on the leaf area index and dry matter accumulation of soybeans, and nitrogen fertilizer has a greater impact on leaf formation and dry matter accumulation than water. Liang et al. (2021) believes through research that high fertilization can promote root water absorption to a certain extent, and high irrigation can promote nutrient absorption by maize roots within a certain range. However, only moderate water and fertilizer levels can improve water and fertilizer utilization efficiency.

Sugar beet is a high-quality, high-yield, and juicy feed crop, with both root tubers and stem leaves serving as feed. It is the most productive feed crop in temperate climate regions and has important economic value. In this article, sugar beet is used as a representative crop for ecological agriculture, and the arid area of Ningxia is used as an experimental area. Through theoretical and empirical research on the coupling model of water and fertilizer, the optimal combination plan of water and fertilizer under different yields is proposed to explore reasonable irrigation and fertilization strategies in arid areas.

Materials and methods

Experimental area and soil conditions

This experimental site is located in Chaiqiao Village, Malianqu Township, Litong District, Wuzhong City, Ningxia Autonomous Region, China, at 37°59′N and 106°11′E,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_16831695

with an elevation of 1127.4 m. The experimental field is made of silty loam soil, with dry bulk density of 1.58 g/cm^3 and a field water holding rate of 52.52%. The total salt content of the soil is 2.38 g/kg, available N is 110 mg/kg, available P is 33.2 mg/kg, available K is 118 mg/kg, total N is 0.85 g/kg, total P is 0.76 g/kg, total K is 21.8 g/kg, organic matter is 16.8 g/kg, and PH value is 8.02.

Experimental parameters

During the experiment, a three-factor quadratic regression universal rotation combination design method was used. Study the effects of different irrigation rates, nitrogen and potassium application rates, as well as their coupling on the growth, development, physiology, and yield of sugar beets under film irrigation conditions, and propose optimized combinations of irrigation water, nitrogen, and potassium fertilizers for different yields.

Based on the actual situation of local agricultural production and farmers' practical experience, the experimental parameters are determined as irrigation water quota, pure nitrogen application amount, and pure potassium application amount. Among them, the upper limit (Z_{21}) and lower limit (Z_{11}) of irrigation water quota are determined as 80 m^3/667 m^2 and 20 m^3/667 m^2 respectively; The upper limit (Z_{22}) and lower limit (Z_{12}) of pure nitrogen are determined as 54.0 kg/667 m^2 and 26.0 kg/667 m^2, respectively; The upper limit (Z_{23}) and lower limit (Z_{13}) of pure potassium are determined as 70 kg/667 m^2 and 50 kg/667 m^2, respectively. The zero level (Z_{pj}) and change interval (Δ_j) of each parameter are:

$$Z_{pj} = \frac{Z_{1j} + Z_{2j}}{2} \quad \text{(Eq.1)}$$

$$\Delta_j = \frac{Z_{2j} - Z_{pj}}{\gamma} \quad \text{(Eq.2)}$$

Here, Z_{1j} is the lower limit of experimental parameters; Z_{2j} is the upper limit of experimental parameters; j is the serial number of the experimental parameter; γ is the star arm, and its calculation under quadratic regression universal rotation is as follows:

$$\gamma = 2^{\frac{m}{4}} \quad \text{(Eq.3)}$$

Here, m is the number of experimental parameters. Because $m = 3$, we can calculate $\gamma = 1.682$. After normalizing the experimental parameters, the following results were obtained:

$$x_j = \frac{Z_{2j} - Z_{1j}}{\Delta_j} \quad \text{(Eq.4)}$$

The configuration of experimental parameters in the quadratic regression rotation analysis during the experimental process is shown in *Table 1*.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_16831695

Table 1. *Configuration of experimental parameters in quadratic regression rotation analysis*

Level	Experimental parameters		
	Water (m^3/667m^2)	**Nitrogen (kg/667m^2)**	**Potassium (kg/667m^2)**
$+\gamma$	80.00	54.00	70.00
+1	67.84	48.30	65.90
0	50.00	40.00	60.00
-1	32.16	31.70	54.10
$-\gamma$	20.00	26.00	50.00

Experimental field configuration

A total of 20 experimental fields are set up, with each field uniformly sized at 18 m in length, 1.2 m in width, and 21.6 m^2 in area. The irrigation channels are arranged in order in the field, and each experimental field is irrigated with small furrow film. In the experimental, sugar beet variety is FF10000, the sowing rate is 300 g/667 m^2, which was sown and covered with plastic film on May 13th, interbedded on May 30th, fixed on June 9th, applied 60% fertilizer for the first time on June 21st, and 40% fertilizer for the second time on July 31st. On August 2nd and August 27th, the plots were irrigated with non throat measuring weirs. During the experiment, the weather conditions remained dry and rainy. No organic or inorganic fertilizers were applied in each experimental field. The layout plan of the experimental field and irrigation canal is shown in *Figure 1*.

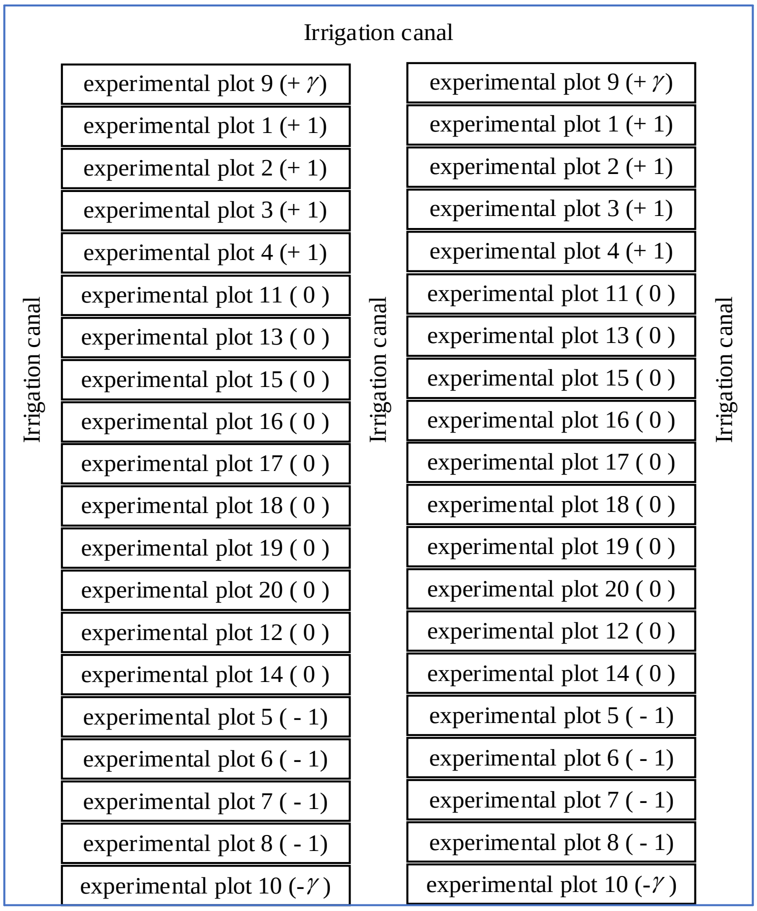

Figure 1. *Layout plan of experimental field and irrigation canal*

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Water fertilizer coupling model

The water fertilizer coupling model used for irrigating sugar beets on film in the experimental field can be represented by a quadratic regression rotation model, as follows:

$$y' = b_0 + \sum_{j=1}^{m} b_j x_j + \sum_{i<j} b_{ij} x_i x_j + \sum_{j=1}^{m} b_{jj} x_j^{2} \quad \text{(Eq.5)}$$

Here, *y*' is the estimated value of quadratic regression, specifically referring to sugar beet yield; x_j represents the three parameters that affect sugar beet yield in the water fertilizer model, namely irrigation water amount, nitrogen fertilizer application amount, and potassium fertilizer application amount; b_j is the first-order coefficients of each parameter in the regression model; b_{ij} is the interaction coefficient of each parameter in the regression model; b_{jj} is the quadratic coefficients of each parameter in the regression model; *m* is the total number of parameters; *j* is the parameter sequence number.

From the model shown in *Equation 5*, we can see that the influencing factors of sugar beet yield comprehensively consider the one-time effects of irrigation water amount, nitrogen fertilizer application amount, and potassium fertilizer application amount, as well as the interactive effects of three influencing factors.

Experimental results

Raw experimental data for quadratic regression

We use HYDRUS software to carry out experiment. According to the water fertilizer coupling model shown in *Equation 5*, the raw data obtained from the quadratic regression rotation analysis method are shown in *Table 2*.

Table 2. *Raw data of quadratic regression rotation analysis method*

No.	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	x_1^2	x_2^2	x_3^2	*y* (kg/667 m²)
1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	1	1	1	1	1	1	7546.98
2	1	1	1	-1	1	-1	-1	1	1	1	9003.13
3	1	1	-1	1	-1	1	-1	1	1	1	6036.28
4	1	1	-1	-1	-1	-1	1	1	1	1	6101.81
5	1	-1	1	1	-1	-1	1	1	1	1	6948.60
6	1	-1	1	-1	-1	1	-1	1	1	1	6947.68
7	1	-1	-1	1	1	-1	-1	1	1	1	6744.11
8	1	-1	-1	-1	1	1	1	1	1	1	6947.92
9	1	1.682	0	0	0	0	0	2.828	0	0	7301.32
10	1	-1.682	0	0	0	0	0	2.828	0	0	5943.99
11	1	0	1.682	0	0	0	0	0	2.828	0	7238.53
12	1	0	-1.68	0	0	0	0	0	2.828	0	7579.92
13	1	0	0	1.682	0	0	0	0	0	2.828	8206.78
14	1	0	0	-1.68	0	0	0	0	0	2.828	7732.26
15	1	0	0	0	0	0	0	0	0	0	8898.48
16	1	0	0	0	0	0	0	0	0	0	7907.24
17	1	0	0	0	0	0	0	0	0	0	8415.73
18	1	0	0	0	0	0	0	0	0	0	7877.74
19	1	0	0	0	0	0	0	0	0	0	7223.09
20	1	0	0	0	0	0	0	0	0	0	8885.10

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DOI: http://dx.doi.org/10.15666/aeer/2202_16831695

Based on the relevant data in *Table 2*, combined with the water fertilizer coupling model shown in *Equation 5*, the water fertilizer coupling equation for sugar beet yield in this article can be obtained, as shown in *Equation 6:*

$$\begin{aligned} y = 8210.26 + 247.68x_1 + 295.94x_2 - 67.83x_3 \\ + 525.97x_1x_2 - 164.85x_1x_3 - 148.24x_2x_3 \\ - 610.63x_1^2 - 332.58x_2^2 - 134.52x_3^2 \end{aligned} \quad \text{(Eq.6)}$$

Univariate analysis

Due to the dimensionless linear coding transformation, the partial regression coefficients are no longer affected by the size and unit of factor values, which means they have been standardized. Its size can directly reflect the degree of influence of variables on yield. Taking into account the partial regression coefficient and t-test results, it can be concluded that the order of influence of various factors on yield in the experiment is nitrogen application rate (x_2) > irrigation water amount (x_1) > potassium application rate (x_3).

Fix two of the three factors of water, nitrogen, and fertilizer in the regression model at the zero level, and obtain the regression sub model of single factor on yield as follows:

Water: $y_1 = 8210.25 + 247.68x_1 - 610.63x_1^2$

Nitrogen: $y_2 = 8210.25 + 295.94x_2 - 332.58x_2^2$

Potassium: $y_3 = 8210.25 - 67.83x_3 - 134.51x_3^2$

Based on partial regression sub model mentioned above, let $\frac{dy_1}{dx_1} = 0$, $\frac{dy_2}{dx_2} = 0$, $\frac{dy_3}{dx_3} = 0$, we can get the results when $x_1 = 0.20$, $x_2 = 0.44$, and $x_3 = \text{-}0.25$ production has a maximum value: $y_1 = 8235.36$ kg/667 m^2, $y_2 = 8276.08$ kg/667 m^2, $y_3 = 8218.8$ kg/667 m^2.

Further observation of the single effect of three factors on sugar beet yield is shown in *Figures 2, 3,* and *4,* respectively. The relationship between beet yield and irrigation water volume is shown in *Figure 2*. From *Figure 2,* it can be seen that the relationship between sugar beet yield and irrigation amount under film irrigation shows an upward convex parabolic shape within the experimental range. When the irrigation quota increases from 20 m^3/667 m^2 (-1.682 level) to 53.57 m^3/667 m^2 (0.02 level), the yield increases from 6066.104 kg/667 m^2 to 8235.36 kg/667 m^2, indicating that the increase in yield per unit of irrigation is 64.62 kg/m^3; When the irrigation amount is higher than 53.57 kg/667 m^2(0.02 level), the yield slowly decreases from 8235.362 kg/667 m^2 to 6899.3 kg/667 m^2, which means that the yield decreases by 50.55 kg/m^3 when the unit water volume is increased.

The relationship between sugar beet yield and nitrogen fertilizer application is shown in *Figure 3*. From *Figure 3,* it can be seen that the relationship between sugar beet yield and nitrogen application rate under film irrigation showed an upward convex parabolic shape within the experimental range. When the nitrogen application rate increased from 26 kg/667 m^2 (-1.682 level) to 43.65 kg/667 m^2 (0.04 level), the yield increased from 6771.575 kg/667 m^2 to 8235.36 kg/667 m^2, indicating an increase in yield of 82.93 kg per unit of nitrogen application; When the nitrogen application rate exceeds

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DOI: http://dx.doi.org/10.15666/aeer/2202_16831695

43.65 kg/667 m^2 (0.04 level) and reaches 54 kg/667 m^2 (+1.682 level), the yield decreases from 8235.36 kg/667 m^2 to 7767.11 kg/667 m^2, indicating a yield reduction of 45.24 kg when the unit nitrogen application rate is increased.

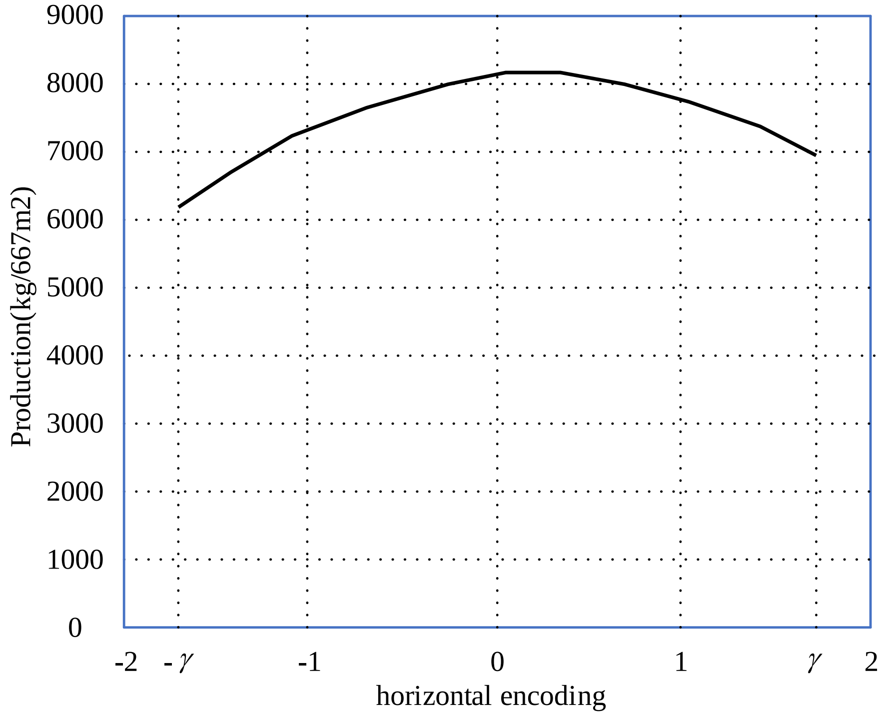

Figure 2. *Changes in the relationship between beet yield and irrigation water volume*

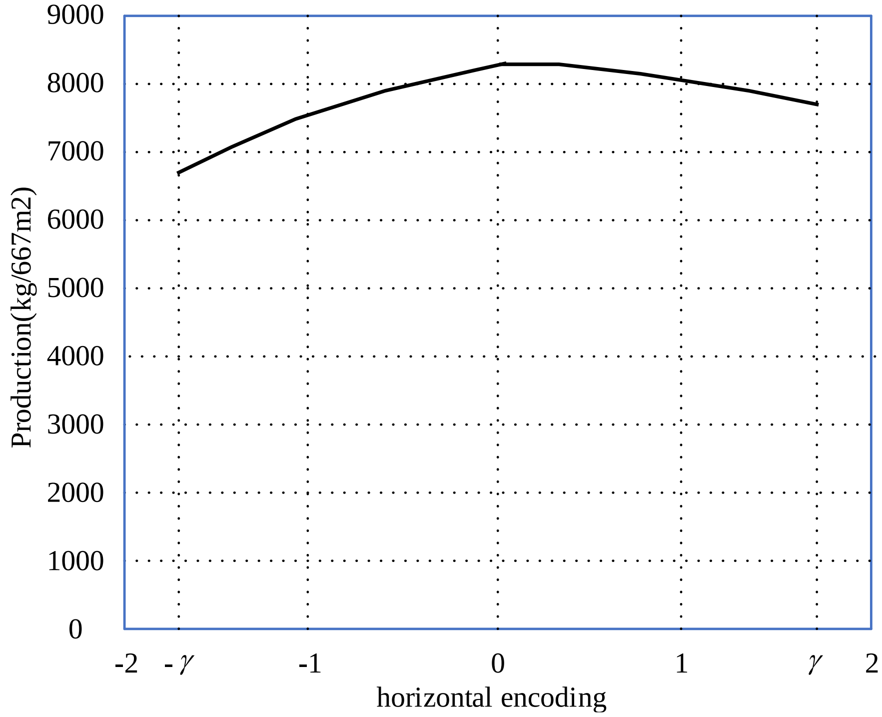

Figure 3. *Changes in the relationship between sugar beet yield and nitrogen fertilizer application*

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The relationship between sugar beet yield and potassium fertilizer application is shown in *Figure 4*. From *Figure 4,* it can be seen that the relationship between sugar beet yield and potassium application under film irrigation also shows an upward convex parabolic shape within the experimental range. When the potassium application rate increases from 50k g/667 m^2 (-1.682 level) to 58.53 kg/667 m^2 (-0.02 level), the yield increases from 7943.79 kg/667 m^2 to 8235.3 kg/667 m^2, which means that the yield increase value by increasing the unit potassium application rate is 34.17 kg; When the potassium application rate exceeds 58.53 kg/667 m^2 (-0.02 level) and increases to 70 kg/667 m^2 (+1.682 level), the yield decreases from 8235.3 kg/667 m^2 to 7715.61 kg/667 m^2, indicating a yield reduction of 45.3 kg when the unit potassium application rate is increased.

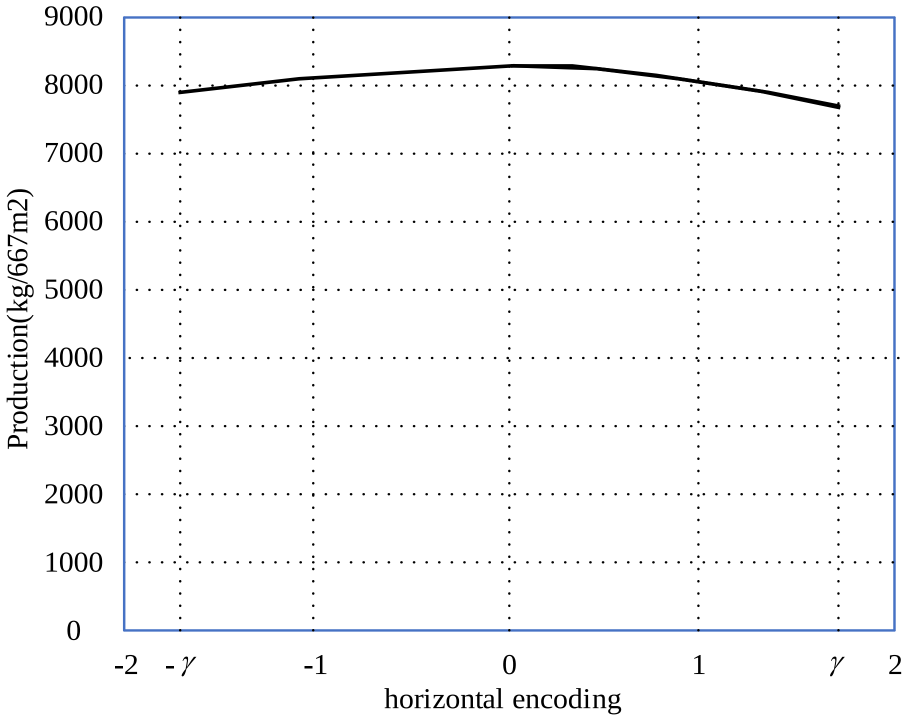

Figure 4. *Changes in the relationship between sugar beet yield and potassium fertilizer application*

Summarize the estimated results of the above process, as shown in *Table 3*.

Table 3. *Estimated beet yield under single factor influence (kg/667 m^2)*

Level	Estimation results of beet yield under different factors		
	Estimation results of sugar beet yield under the influence of irrigation water volume	**Estimation results of sugar beet yield under the influence of nitrogen fertilizer application amount**	**Estimation results of sugar beet yield under the influence of potassium fertilizer application amount**
+γ	6899.3	7767.11	7715.61
+1	7847.3	8173.61	8007.91
0	8210.25	8210.25	8210.25
-1	7351.94	7581.73	8143.57
-γ	6066.104	6771.57	7943.79

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The interaction between two factors

In the previous work, the single impact of three factors: irrigation water amount, nitrogen fertilizer application amount, and potassium fertilizer application amount on sugar beet yield was analyzed. In the following work, we will further explore the interaction between two factors on the yield of sugar beets.

According to the t-test results of the interaction coefficient of the regression equation, it can be seen that the interaction between irrigation water volume and nitrogen fertilizer application has reached a significant level. When x_3 is fixed at the zero level, the following water nitrogen interaction equation can be obtained:

$$y = 8210.26 + 247.68x_1 + 514.3295.94x_2 - 164.85x_1x_2 - 610.63x_1^2 - 332.58x_2^2 \text{ (Eq.7)}$$

According to the calculation, the impact of the interaction between irrigation water volume and nitrogen fertilizer application on sugar beet yield is shown in *Table 4*.

Table 4. *The interaction between irrigation water volume and nitrogen fertilizer application on sugar beet yield*

Item		x_1					Parameters		
		-1.682	-1	0	1	+1.682	X_p	s	C_v (%)
x_2	-1.682	6115.47	6322.28	6066.11	5144.79	4134.94	5556.72	915.00	16.47
	-1	6797.95	7249.40	7351.95	6789.34	6024.13	6842.55	524.32	7.66
	0	6771.58	7581.74	8210.26	8173.62	7767.12	7700.86	584.19	7.59
	+1	5523.95	6692.82	7847.31	8636.64	8288.85	7337.91	1211.18	16.51
	+1.682	3972.59	5386.11	6899.31	7747.35	7944.20	6389.91	1685.90	26.38
Parameters	X_p	5836.31	6646.47	7274.99	7238.35	6831.85			
	S	1167.09	856.45	838.26	1315.74	1743.61			
	C_v (%)	20.00	12.89	11.52	18.18	25.52			

From *Table 4*, it can be seen that under a certain amount of potassium fertilizer application, the interaction between irrigation water amount and nitrogen fertilizer application results in the highest yield of sugar beet: when irrigation water amount is 6066.11 and nitrogen fertilizer is 6771.58, the yield of sugar beet is the highest. That is, under the interaction of irrigation water amount at +1 level and nitrogen fertilizer application at + 1 level, the yield of sugar beet is 8636.64 kg/667 m^2.

Calculation of the optimal water and fertilizer plan

Based on the established mathematical model for optimizing the coupling of water and fertilizer in sugar beets, a computer program is developed. Seven levels (-1.682, -1, -0.5, 0, +0.5, +1, +1.682) are taken between -1.682 and +1.682, and the optimal combination scheme under different objectives is simulated on the computer.

Through simulation, it was found that there are 168 combination schemes for irrigation water amount, actual nitrogen fertilizer amount, and potassium fertilizer application amount when the yield target of sugar beet is between 6000 and 7000 kg/667 m^2, as shown in *Table 5*. From the results in *Table 5*, it can be seen that when the yield target of sugar beets is 6000~7000 kg/667 m^2, the irrigation water amount should be 37.10~52.66 m^3/667 m^2, the nitrogen fertilizer application amount should be 32.27~39.25 kg/667 m^2, and the potassium fertilizer application amount should be 58.36~63.36 kg/667 m^2.

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DOI: http://dx.doi.org/10.15666/aeer/2202_16831695

Table 5. *Optimization plan and frequency for 667 m² beet yield of 6000-7000 kg*

Level	x_1		x_2		x_3	
	Times	**Frequency**	**Times**	**Frequency**	**Times**	**Frequency**
-1.682	36	0.2143	42	0.3095	22	0.1310
-1.0	44	0.2619	34	0.2024	20	0.1190
-0.5	16	0.0952	24	0.1429	20	0.1190
0.0	16	0.0952	16	0.0952	26	0.1548
0.5	16	0.0952	10	0.0595	24	0.1429
1.0	16	0.0952	16	0.0952	22	0.1310
1.682	24	0.1429	16	0.0952	34	0.2024
Sum-times	168	1.0	168	1.0	53168	1.0
Mean	-0.2868		-0.5092		0.1440	
Standard deviation	0.4713		0.4535		0.4542	
95% Confidence interval	-0.7227～0.1491		-0.9287～0.0898		-0.2761～0.5640	
Scale	37.1～52.66		32.27～39.25		58.36～63.36	

Furthermore, through simulation, it was found that there are 288 combinations of irrigation water quantity, actual nitrogen fertilizer amount, and potassium fertilizer application amount when the sugar beet yield target is between 7000 and 8000 kg/667 m^2. The results are shown in *Table 6*.

Table 6. *Optimization plan and frequency for 667 m² beet yield of 7000-8000 kg*

Level	x_1		x_2		x_3	
	Times	**Frequency**	**Times**	**Frequency**	**Times**	**Frequency**
-1.682	0	0	8	0.0278	28	0.0972
-1.0	44	0.1528	46	0.1597	34	0.1181
-0.5	82	0.2847	66	0.2292	40	0.1389
0.0	52	0.1806	54	0.1875	40	0.1389
0.5	40	0.1389	44	0.1528	44	0.1528
1.0	40	0. 1389	34	0.1181	56	0.1944
1.682	30	0.1042	36	0.1250	46	0.1597
Sum-times	288	1.0	288	1.0	288	1.0
Mean	0.0884		0.0837		0.1885	
Standard deviation	0.3378		0.3648		0.4236	
95% confidence interval	-0.2240～-0.4008		-0.2537～0.4211		-0.2033～0.5803	
Scale	46.0～57.15		37.89～43.5		58.79～63.45	

From the results in *Table 6*, it can be seen that when the yield target of sugar beets is 7000~8000 kg/667 m^2, the irrigation water amount should be 46.00~57.15 m^3/667 m^2, the nitrogen fertilizer application amount should be 37.89~43.50 kg/667 m^2, and the potassium fertilizer application amount should be 58.79~63.45 kg/667 m^2.

Furthermore, through simulation, it was found that there are 108 combination schemes for irrigation water amount, actual nitrogen fertilizer amount, and potassium fertilizer application amount when the yield target of sugar beet is between 8000 and 9000 kg/667 m^2, as shown in *Table 7*. From the results in *Table 7*, it can be seen that when the yield target of sugar beets is 8000~9000 kg/667 m^2, the irrigation water amount should be 57.31~64.10 m^3/667 m^2, the nitrogen fertilizer application amount

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DOI: http://dx.doi.org/10.15666/aeer/2202_16831695

should be 45.08~48.68 kg/667 m^2, and the potassium fertilizer application amount should be 54.93~58.46 kg/667 m^2.

Table 7. *Optimization plan and frequency for 667 m^2 beet yield of 8000-9000 kg*

Level	x_1		x_2		x_3	
	Times	Frequency	Times	Frequency	Times	Frequency
-1.682	0	0	0	0	22	0.2037
-1.0	0	0	0	0	24	0.2222
-0.5	0	0	0	0	22	0.2037
0.0	30	0.2778	20	0.1852	20	0.1852
0.5	40	0.3704	30	0.2778	16	0.1481
1.0	28	0.2593	34	0.3148	4	0.037
1.682	10	0.1123	24	0.2075	0	0
Sum-times	108	1.0	108	1.0	108	1.0
Mean	0.6002		0.8275		-0.5556	
Standard deviation	0.2056		0.2339		0.3201	
95% confidence interval	0.410～0.7903		0.6112～1.0438		-0.8516～-0.2595	
Scale	57.31～64.1		45.08～48.68		54.93～58.46	

Conclusions

In order to achieve the sustainable development of ecological agriculture in the Ningxia region of China, a water fertilizer coupling model for sugar beet irrigation on film was established, taking the sugar beet irrigation problem in the region as the research object. This model is based on the quadratic regression rotation method, taking into account the effects of irrigation water, nitrogen fertilizer application, potassium fertilizer application on sugar beet yield, and considering the interaction of three factors. The experimental results of 20 experimental fields showed that the three factors affecting sugar beet yield, from strong to weak, were nitrogen fertilizer application amount, irrigation water amount, and potassium fertilizer application amount, and there was a strong interaction between irrigation water amount and nitrogen fertilizer application amount on sugar beet yield.

Based on the target difference in sugar beet yield, the optimal solution for coupling water and fertilizer was calculated. The results are as follows: firstly, when the sugar beet yield target is between 6000 and 7000 kg/667 m^2, the irrigation water amount should be between 37.10 and 52.66 m^3/667 m^2, the nitrogen fertilizer application amount should be between 32.27 and 39.25 kg/667 m^2, and the potassium fertilizer application amount should be between 58.36 and 63.36 kg/667 m^2. Secondly, when the sugar beet yield target is between 7000 and 8000 kg/667 m^2, the irrigation water amount should be between 46.00 and 57.15 m^3/667 m^2, the nitrogen fertilizer application amount should be between 37.89 and 43.50 kg/667 m^2, and the potassium fertilizer application amount should be between 58.79 and 63.45 kg/667 m^2. Thirdly, when the yield target of sugar beets is 8000~9000 kg/667 m^2, the irrigation water amount should be 57.31~64.10 m^3/667 m^2, the nitrogen fertilizer application amount should be 45.08~48.68 kg/667 m^2, and the potassium fertilizer application amount should be 54.93~58.46 kg/667 m^2.

Based on this, the strategy for sugar beet irrigation in arid areas can be obtained: during the wet season, the irrigation water amount should be appropriately increased and the amount of nitrogen fertilizer applied should be reduced; During the dry season, the amount of irrigation water should be appropriately reduced and the amount of nitrogen fertilizer applied should be increased. Through this flexible adjustment, sustainable cultivation of sugar beets in arid areas can be achieved, and coordination between natural environment and agricultural production can be achieved.

Acknowledgements. This study was funded by the High Level Undergraduate Education Project of Higher Education Institutions in the entire region (Ning Jiao Gao Ban [2021]7), which is a first-class undergraduate major construction point at the autonomous region level (Civil Engineering Major).

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http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_16831695