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Coupling Mode of Water and Fertilizers under Different Soil Erosion Thicknesses in the Black Soil Region of Northeast China

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Abstract: This paper is focused on the coupling mode of water and fertilizers under different soil erosion thicknesses in black soil region of Northeast China. The 4-D-optimum orthogonal design (416-A) is adopted to conduct the experiment under the soil erosion thicknesses of 0 and 15 cm so that the coupling modes of water and fertilizers under the two thicknesses are established. The results show that water, along with N, P, and K, affects soybean yield, but the intensity varies with soil erosion thickness. Under the soil erosion thickness of 0 cm, the order is: W>P>N>K. Under the soil erosion thickness of 15 cm, the order is: N>W>P>K. With the increase in soil erosion thickness, the effect of W is reduced, whereas that of fertilizations increase. The research results can provide the theoretical basis for soil erosion prevention and control in the black soil region.

Keywords: black soil, soil erosion thickness, coupling mode of water and fertilizers

1 Introduction

Soil erosion is one of the most widespread ecological problems in the world. The black soil region of Northeast China is the most important grain production base and one of six soil erosion regions in China. The increasing soil erosion presents the problem of determining the reasonable coupling mode of water and fertilizers under different degrees of soil erosion, which is missing at present. In this study, soil erosion thicknesses of 0 and 15 cm are selected to conduct the coupling experiment on soybean, so that the coupling modes of water and fertilizers under the two thicknesses are established. The research results can provide a theoretical basis for the efficient use of water and soil resources.

2 Experiment Design

The experiment is conducted in a mobile rain-proof shed. The 4-D-optimum orthogonal design is adopted by setting N, P, K, W as the four factors. The level codes

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of each factor are shown in Table 1.

Table 1. Level codes of experiment factors

Coded value				Actual value			
x_1	x_2	x_3	x_4	W (%)	N (kg/hm^2)	P (kg/hm^2)	K (kg/hm^2)
1.685	1.685	1.685	1.784	90	280	150	180
1	1	1	0.644	81.87	235.28	125.61	127.83
0	0	0	-0.908	70	170	90	56.81
-1	-1	-1	-1.494	58.13	104.72	54.39	30
-1.685	-1.685	-1.685		50	60	30	

3 Results and Discussion

3.1 Coupling Equations of Water and Fertilizers under different soil erosion thicknesses

The regression models of soybean yield on W, N, P, and K under the two thicknesses are established as follows:

$$y^{(1)} = 55.00 + 7.75x_1 + 1.07x_2 + 0.29x_3 - 2.07x_4 + 1.53x_1x_2 + 0.44x_1x_3 + 0.75x_1x_4$$
$$+1.30x_2x_3 + 0.08x_2x_4 + 0.39x_3x_4 - 2.59x_1^2 + 5.32x_2^2 - 3.13x_3^2 - 0.28x_4^2 \quad (1)$$

$$y^{(2)} = 32.39 + 5.61x_1 + 1.34x_2 + 0.28x_3 - 1.77x_4 + 1.83x_1x_2 + 0.57x_1x_3 + 0.80x_1x_4$$
$$+1.61x_2x_3 - 1.18x_2x_4 + 0.43x_3x_4 - 3.82x_1^2 + 10.89x_2^2 - 2.46x_3^2 - 0.04x_4^2 \quad (2)$$

where $y^{(1)}$ and $y^{(2)}$ refer to soybean yield under the soil erosion thicknesses of 0 and 15 cm; x_1, x_2, x_3, and x_4 refer to the coded values of W, N, P, K, respectively.

The variance analysis results of both equations are significant. The results of the regression coefficient test show that all four factors and their interactions influence soybean yield and that the significant items in the two equations are the same. These significant items are the linear terms of W, N, and K; the interactive terms of W and N, W and K, and N and P; as well as the quadratic terms of W, N, and P. The regression equations can objectively reflect the influence of irrigation and fertilization amounts on soybean yield under different soil erosion thicknesses and can serve as the basis for prediction.

3.2 Analysis of Single Factor Effects

The single factor effects of the four factors under different soil erosion thicknesses are shown in Figure 1. Figure 1(a) shows that when the N, P, and K are fixed at zero level, soybean yield first increases and then decreases under both soil erosion thicknesses with the increase in W. By contrast, soybean yield exhibits a more negligible change under the soil erosion thickness of 15 cm than 0 cm, which indicates a reducing effect of W with low soil fertility. The single factor effects of N, P, K under different soil erosion thicknesses can be analysed similarly.

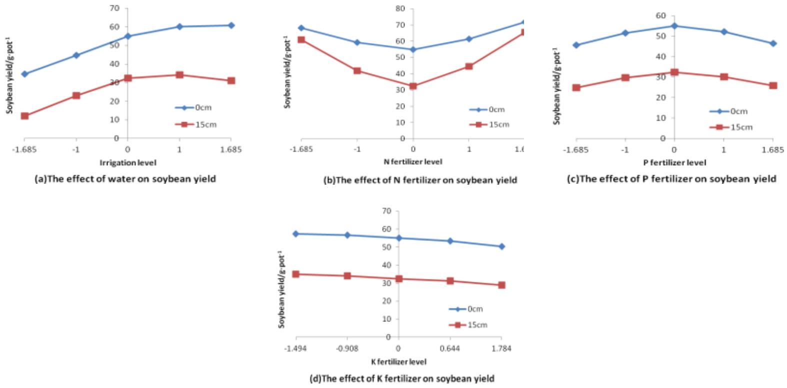

Fig. 1 Analysis of single factor effects

3.3 Analysis of Interaction Effects between Factors

On the basis of the results of the regression coefficient test, the interaction terms of W and N, W and K, N and P are selected to analyze interaction effects. The coupling effect diagrams under different soil erosion thicknesses are shown in Figure 2 and Figure 3. Figure 2(a) shows that under the soil erosion thickness of 0 cm, soybean yield increases with the increase in W when N remains constant, whereas the yield first increases and then decreases with the increase in N when W remains constant. The maximum yield appears in the level combination of high W and high N. Figure 3(a) shows that under the soil erosion thickness of 15 cm, soybean yield has a more sensitive response to W and N. When N is fixed at a higher level interval of (0, 1.685), soybean yield increases with the increase in W. By contrast, when N is fixed in a lower level interval of (-1.685, 0), soybean yield first increases and then decreases with the increase of W. Meanwhile, soybean yield first decreases and then increases with the increase in N when W remains constant, and the maximum yield appears in the level combination of high W and high N. The interaction effects of W and K, N and P can be analyzed similarly.

According to the above analysis, the ideal coupling mode of water and fertilizers should be high N, proper P, and low K under the condition of sufficient W, which could help increase soybean yield.

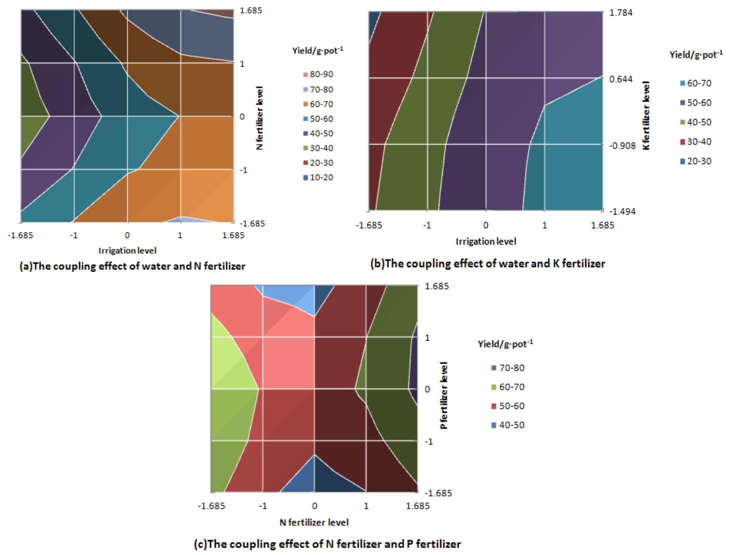

Fig. 2 Coupling effect diagrams at a soil erosion thickness of 0 cm

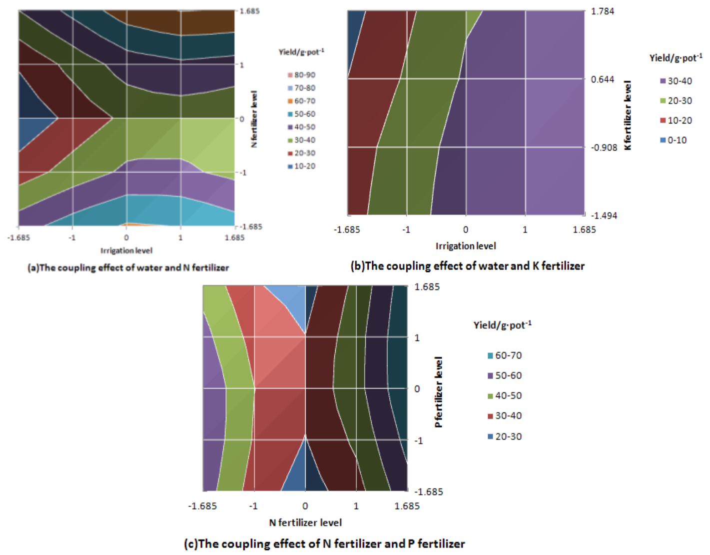

Fig. 3 Coupling effect diagrams at a soil erosion thickness of 15 cm

3.4 Optimum Coupling Mode of Water and Fertilizers

The frequency analysis is used to identify the optimum coupling mode of water and fertilizers, and the results are shown in Table 2.

Table 2. Results of frequency statistics at different soil erosion thicknesses

		x_1（W）	x_2（N）	x_3（P）	x_4（K）
0 cm	Mean	1.098	1.028	0.239	-0.387
	Standard deviation	0.618	1.323	0.899	1.197
	95% confidence interval	（0.919，1.277）	（0.641，1.409）	（-0.022，0.500）	（-0.735，-0.040）
15 cm	Mean	0.835	1.049	0.267	-0.207
	Standard deviation	0.688	1.331	1.039	1.225
	95% confidence interval	（0.646，1.025）	（0.682，1.416）	（-0.019，0.554）	（-0.544，0.131）

Converted the optimum levels under the two thicknesses into actual values so that we can get the optimum coupling modes. A comparison under the two thicknesses reveals that W becomes smaller, whereas N, P, and K become greater, and the maximum yield reduces.

4 Conclusion

In this paper, we establish the coupling modes of water and fertilizers under the soil erosion thicknesses of 0 cm and 15 cm in the black soil region of China. The results show that W, N, P, and K and their interactions all influence soybean yield, but the intensity varies with the soil erosion thickness. With the increase in soil erosion thickness, the effect of W reduces, whereas that of fertilizations increase.

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