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Comprehensive evaluation based on improved topsis model of fluorescence parameters of direct-seeding rice at heading and flowering stage in cold and black soil region

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Abstract. In order to study the influence of water and fertilizer utilization mode in cold and black soil region on chlorophyll fluorescence parameters of direct-seeding rice, the direct-seeding rice for test-pit experiment was used as the research object and the fluorescence parameters including F_0, F_m, F_v/F_m, F_v/F_0 and $\Phi PSII$ of rice leaves in heading and flowering stage were carried out with multi index comprehensive evaluation by using the orthogonal test method set with four factors including irrigation, nitrogen, phosphate and potash and the improved TOPSIS (technique for order preference by similarity to ideal solution) model given with combined weights, meanwhile the fluorescence parameters were also evaluated by using the TOPSIS model and grey relational degree model to carry out the consistency analysis with the above evaluation. The results showed that the comprehensive score of chlorophyll fluorescence parameters of the direct-seeding rice in heading and flowering stage with the water and fertilizer utilization mode of controlled irrigation, high nitrogen, high phosphorus and high potassium was the best, and the comprehensive evaluation results of chlorophyll fluorescence parameters of the rice in cold region evaluated by using the improved TOPSIS model were more relatively ideal, which can be used as a more convenient and accurate method for the comprehensive evaluation of chlorophyll fluorescence parameters.

Key words. Cold and black soil region, direct-seeding rice, chlorophyll fluorescence, improved

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TOPSIS model.

1. Introduction

Chlorophyll fluorescence technique is an important way to analyze the response mechanism of plant to environmental stress. The changes in all photosynthetic processes could be basically detected by studying the chlorophyll fluorescence[1]−[2].Chlor fluorescence analysis technology is known as a rapid and non-invasive probe for determining the photosynthetic function of leaves[3]. While as the main factor of limiting plant growth and development[4]−[5], water and fertilizer play an important role in plant chlorophyll fluorescence. The suitable ratio of water and fertilizer can not only affect the chlorophyll fluorescence to promote photosynthesis and increase dry material accumulation, but also save water and fertilizer resources and reduce environmental pollution.

There were a lot of researches on the effects of moisture[6]−[7], nitrogen fertilize[8] and water-nitrogen interaction[10]−[11] on chlorophyll fluorescence kinetics parameters , but there was few comparative studies on the effects of multi factors including fertilizers of nitrogen, phosphate, potash and water on the characteristics of chlorophyll fluorescence of rice grown in cold and black soil. Based on this, with the different water and fertilizer combinations, the test-pit experiments were carried out in this paper to make a comprehensive evaluation on the chlorophyll fluorescence parameters of direct-seeding rice leaves in heading and flowering stage and find the best water and fertilizer combination at the best level of chlorophyll fluorescence.

2. Material and Method

2.1. General Situation of Experimental Area

The experiment was carried out in Rice Irrigation Experiment Center of Heilongjiang Province from May 2016 to October 2016, and the station (east longitude 12544, north latitude 4563) is located in Hepin town of Qing'an County, which is a distribution area of typical cold and black soil with perennial mean temperature of 2.5. Climate characteristics belong to cold temperate continental monsoon climate. The soil type is the white paddy soil with the bulk density of 1.01g?cm^{-3}and the porosity of 61.8%.

2.2. Experimental Materials and Design

The variety of rice for experiment was Longqing rice of No. 2. The fertilizers for experiment were urea (N content of 46%) and diammonium phosphate (P_2O_5 content of 46%, N content of 18%), potassium sulfate (K_2O content of 51%). Experiment was conducted in the test-pit with full-automatic awning. Each micro-plot covered an area of 4m^2. There was no seepage in cement pit. The direct-seeding cultivation

was adopted by the experiment with the same field management conditions and technical measures such as rice varieties, planting, plant protection, medicine and others.

The experiment selected 4 factors, respectively as W(irrigation way), N(nitrogen), P(phosphate)and K(potash), which were respectively divided into three levels. Irrigation ways included controlled irrigation (W1), intermittent irrigation (W2) and flood irrigation (W3); the nitrogen application rate included 140kg/hm^2 (N1); the phosphat application rate included 55 kg/hm^2 (P1),35kg/hm^2(P3); the potassium application rate included 100kg/hm^2 (K1), 80kg/hm^2 (K2) and 60kg/hm^2 (K3). The experiment was conducted with $L_9(3)^4$orthogonal design experiment and the nine treatments were respectively as: $W_1N_1P_1K_1$, $W_1N_2P_2K_2$, $W_1N_3P_3K_3$, $W_2N_1P_2K_3$, $W_2N_2P_3K_1$, $W_2N_3P_1K_2$, $W_3N_1P_3K_2$, $W_3N_2P_1K_3$, $W_3N_3P_2K_1$, each of which was repeated for 3 times.

The field was dunked and applied with basal on May 6^{th}, sowing was carried out on May. 10^{th}, and the harvest was carried out on Sept. 20^{th}. The growth period of rice was 123d, which was divided into seedling stage (May. 21^{st}-June. 5^{th}), tillering stage (June. 6^{th}-July. 4^{th}), jointing and booting stage (July. 5^{th}-July. 20^{th}), heading and flowering stage (July. 20^{th}-July. 31^{st}), milky stage (Aug. 1^{st}-Aug. 24^{th}), yellow ripening stage (Aug. 25^{th}-Sept. 20th). The soil moisture regulation standard in different irrigation modes of rice was shown in Table 1.

Table 1. Managements of Soil Moisture Treatments in Growing Periods of Rice

Treatment	Initial Tillering Stage	Vigorously Tillering Stage	Late Tillering Stage	Jointing and Booting Stage	Heading and Flowering Stage
Controlled Irrigation	85%~30	85%~30	60%~0	85%~20	85%~
Intermittent Irrigation	0~30	0~30	0~10	0~30	0~
Flood Irrigation	10~50	10~30	0~10	10~50	10~

Remark: The figures in the table are calculated by mm and the percentage is the value of saturated moisture content of soil.

2.3. Observation Index and Observation Method

When the rice was at flowering stage, with the selection of sunny windless weather, after the dark adaptation treatment of leaf for 30min, the initial fluorescence F_0 and the maximum fluorescence F_m of the photosystem II(PSII) of rice leaves were determined by LI-6400XT photosynthetic instrument to calculate the ratio of variable fluorescence to maximum fluorescence F_v/F_m and the ratio of variable fluorescence to initial fluorescence F_v/F_0; after the photoactivation of the same leaf for 30min, the actual photochemical quantum efficiency of PSII (ϕPSII) with the existence of light was determined.

2.4. Data Processing Method

The average value of each index was carried out with data processing and statistical analysis by using the software such as WPS, Matlab 2014a, SPSS 18.0 and so on.

2.5. Improved TOPSIS Model with Different Weighting Methods

The TOPSIS model is a common method in system decision sequencing. The basic idea of TOPSIS is to calculate the distances between the evaluation objects and the ideal solution and the distances between the evaluation objects and the negative ideal solution with Euclidean distance as the measure, while further calculating relative closeness (C_i) of the distance between the evaluation scheme and the ideal solution, which is used as the comprehensive evaluation index, that is to say, the bigger the C_i is, the better the scheme is[12]. TOPSIS model has the characteristics of simple calculation, reasonable evaluation and flexible application.

Therefore, according to the improvements of the above two points, the improved TOPSIS model based on combination weighting was put forward in this paper, and the detailed steps are as follows:

(1) Construct the decision matrix of original data.

Set up m water and fertilizer utilization modes, each of which is carried out with comprehensive evaluation of n indexes, and then construct the original data decision matrix R=$(x_{ij})_{mn}$, where, x_{ij} represents the original data value of j-th index ini-th water and fertilizer utilization mode, i = 1,2,... ,m j = 1,2,... ,n.

(2)Construct the standardized decision matrix.

The evaluation index can be divided into high priority index and low priority index. In order to ensure the quality of the constructed model and the correctness of the statistical analysis, the original decision matrix is carried out with the treatments of chemotaxis and normalization to obtain the matrix.

For high priority index, there is: $b_{ij}=x_{ij}/x_{max}(j)$.While for low priority index, there is:$b_{ij}=x_{min}(j)/x_{ij}$.

(3)Construct the weighted standard matrix.

The first is to determine the weight of each index $W=(w_1,w_2,\ldots,w_n)$,$\sum_{i=1}^{n} w_i = 1$. After the determination, construct the weighted standard matrix V=WB.

In this paper, the traditional entropy weighting coefficient method and the CRITIC weighting method improved by Wang Lei were respectively used to calculate the weight of each index, denoted as $w=(w_1,w_2,\ldots,w_n)$ and $w'=(w_1',w_2',\ldots,w_n)$. The combination weight $w^*=(w_1^*,w_2^*,\ldots,w_n^*)$ of each index calculated by two kinds of weights requests that the distribution of W_j^* in the space should be as close as possible to w_j and w_j', thus the combination weight calculated according to the principle of minimum relative information entropy[15] is as follows:

$$w_j* = \sqrt{w_j w_j'} \Big/ \sum_{j=1}^{n} \sqrt{w_j w_j'}, (j = 1, 2, \cdots, n)$$

(4)Calculate the ideal solution $V^+$and the negative ideal solution V^-.

(5)Determine the mode for evaluation and the distance between the positive ideal

solution and negative ideal solution.

In this paper, the relative entropy concept proposed by Zhao Meng replaced the Euclidean distance in traditional TOPSIS to calculate the objects for evaluation and the distance between the ideal solution and negative ideal solution.

Where, the bigger the C_i becomes, the closer the i-th mode becomes to the best level. The value of C_i is between 0 and 1. The different water and fertilizer utilization modes can be sorted according to the size order of C_i to obtain the best and the worst water and fertilizer utilization combinations.

3. Statistical Analysis and Results

3.1. Selection of Evaluation Index and Weight Determination of Different Models

The chlorophyll fluorescence indexes of the direct-seeding rice at flowering stage in different water and fertilizer utilization modes are used as the evaluation object. Select the evaluation indexes that have significant effects on the chlorophyll fluorescence function: PSII initial fluorescence (F_0), maximum fluorescence (F_m), PSII photochemical quantum yield (F_v/F_m), PSII potential photochemical quantum efficiency (F_v/F_0), and PSII actual photochemical quantum efficiency ($\Phi PSII$). Among the above indicators, except F_0 being as the low priority index, the rest all belong to the high priority indexes. The detailed observed values of each index are shown in Table 2.

The traditional TOPSIS model, grey correlation degree model and improved TOPSIS model were used to respectively calculate the comprehensive scores of chlorophyll fluorescence in different water and fertilizer utilization modes. Among them, TOPSIS model and grey correlation degree model quote the entropy weighting coefficient method to determine the weighting coefficient of each index, while the improved TOPSIS model adopts the combination weighting method. The weights of each evaluation index determined by the entropy weighting method are 0.239, 0.250, 0.001, 0.021,0.489. The weights determined by the improved CRITIC weighting method are 0.382, 0.230, 0.009, 0.048, 0.330. And the weights determined by the combination weighting method are 0.309, 0.245, 0.003, 0.033, 0.411.

Table 2. Evaluation Index Values Determined in Micro-Plot Experiment

Treatment	Initial Fluorescence (F_0)	Maximum Fluorescence (F_m)	Maximum Quantum Yield (F_v/F_m)	Potential Quantum Efficiency (F_v/F_0)
1	101.700	586.233	0.827	4.764
2	118.350	661.250	0.821	4.587
3	93.500	526.750	0.822	4.634
4	109.650	642.650	0.829	4.861
5	98.800	577.333	0.829	4.843
6	72.800	419.700	0.827	4.765
7	78.600	449.100	0.825	4.714
8	107.250	628.350	0.829	4.859
9	89.300	460.400	0.806	4.156

3.2. Comprehensive Evaluation of Chlorophyll Fluorescence Parameters

The comprehensive evaluation of chlorophyll fluorescence parameters was carried out with the above 5 chlorophyll fluorescence parameters of the direct-seeding rice at heading and flowering stage by using the TOPSIS model improved in this paper, the traditional entropy weighted TOPSIS model and entropy weighted grey correlation degree model. The results evaluation was shown in Figure 1, indicating that the scores obtained by different models have differences. The consistency check was carried out with the comprehensive scores made by the three models and the Kendall's collaborative coefficient reached to 0.960, up to the significant level of 0.01, which indicated that the comprehensive evaluations of fluorescence parameters made by the three models have the statistical consistency.

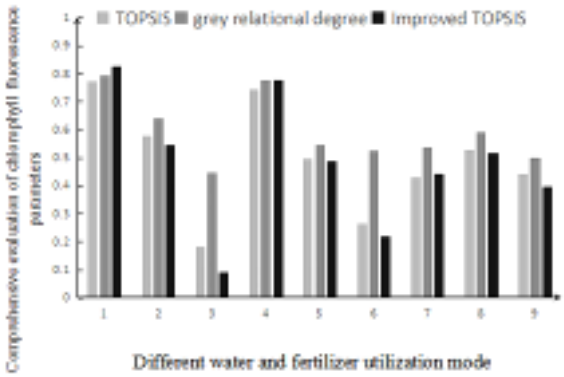

Fig. 1. Comprehensive Evaluation Results of chlorophyll fluorescence of Different Models in Different Water and Fertilizer Utilization Modes

As shown in Figure 1, when the comprehensive evaluations of chlorophyll fluorescence parameters in the three models were the best, all modes were $W_1N_1P_1K_1$, namely, the mode with high nitrogen, high phosphorus and high potassium in the condition of controlled irrigation; when the evaluations were the worst, all modes were $W_1N_3P_3K_3$, namely, the mode with low nitrogen, low phosphorus and low potassium in the condition of controlled irrigation, which indicated that the suitable increase of nitrogen, phosphorus and potassium fertilizer application could make the chlorophyll fluorescence parameters reach the optimal level. Compared with the worst model, F_m in optimal model increased by 11.29%, indicating that the increase of fertilization rate could make the chlorophyll content of leaf in this model be greatly improved to promote the improvement of leaf's fluorescence ability and greatly reduce the damage degree of photosynthetic mechanism; while compared with the worst model, the PSII actual photochemical quantum efficiency in the optimal mode increased by 100% to greatly enhance the efficiency of light energy utilization, which was conducive for the light energy captured by crops to be used better for photosynthesis, which can promote the increase of photosynthetic rate.

4. Conclusions

The direct-seeding rice in cold and black soil region was used as experimental crops, the test-pit experiment was adopted to stimulate the effect of different water and fertilizer modes on fluorescence parameters of rice leaves at heading and flowering stage, and the improved TOPSIS model with combination weight was used to comprehensively evaluate the fluorescence parameters under different water and fertilizer utilization modes, which were also compared with the evaluation results of frequently-used entropy weighted TOPSIS model and entropy weighted grey correlation degree model, thus making the following conclusions:

(1) The multi index weighting was carried out by using two different weighting methods, respectively as the entropy weighting method and the improved CRITIC weighting method, and the obtained weights of each index have differences, while two kinds of weights could be comprehensively considered to carry out the combination weight by using information entropy theory so as to reduce weight imbalance and increase the rationality of weight.

(2) Among the comprehensive scores of fluorescence parameters calculated by the three modes, the optimal modes were $W_1N_1P_1K_1$, while the worst modes were $W_1N_3P_3K_3$. F_m under the optimal mode increased by 11.29% over the worst mode, and the worst PSII actual photochemical quantum efficiency increased by 100% over the worst mode, which indicated that the appropriate increase of fertilization rate under controlled irrigation could make the chlorophyll content of the leaf be greatly improved to promote the improvement of leaf's fluorescence ability and greatly reduce the damage to photosynthetic mechanism, while it also could greatly enhance the efficiency of light energy utilization, thus making the photosynthetic rate of the rice at heading and flowering stage be effectively improved.

The effects of different water and fertilizer utilization modes on the leaf's fluorescence parameters of the direct-seeding rice in cold and black soil region were

explored in this study and the improved TOPSIS model was used to evaluate the comprehensive level of rice leaf's fluorescence parameters under different water and fertilizer utilization modes, while considering the influence of the index weight, the combination weight was introduced, and the comparison and the analysis were carried out with the two commonly used evaluation models to improve the reliability and accuracy of the evaluation results. The results of this study can provide a convenient, reasonable and reliable evaluation model for the evaluation of fluorescence parameters of rice leaves.

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