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Abstract: The effect of agronomic factors including seedling age, transplanting density and net nitrogen ratio on the yield and profit of a single-cropping hybrid late rice (Oryza sativa) cultivar'Yongyou 12' was investigated. The orthogonally rotational combination experimental design was used in setting field parameter test. Regression models assuming yield or profit as the objective function were constructed, and the impact from each individual or combinations of the three agronomic factors on the yield and profit of the crop was estimated. A computer simulation was performed to select the optimized agronomic scheme of growing rice 'Yongyou 12' under the field conditions used in this study.

Key words: Japonica/indica hybrid rice, rice 'Yongyou 12', agronomic factors, yield , profit ,mathematical models, optimization

Since the introduction of the first regression experimental design in the late-1950s, several complex versions have been developed, including the regression for rotary combinational design and regression for d-optimal designs. In agriculture, regression designs are used to develop the optimal agronomic factor schemes for improving agronomic traits. The simplex-lattice and rotation combination designs are used to optimize planting schemes for sweet potato[1,2,3], and the secondary saturation and D-optimal design for soybean, cassava and Dioscorea zingiberensis[4,5,6], and the general rotation combination design for the intercropping system of spring maize and sweet potato [7].

Rice (Oryza sativa) cultivar 'Yongyou 12' is a three-line japonica-type hybrid. In the past few years, the cultivar has been recommended in Tai Zhou, and is very promising for future plantings in this area. According on the Zhejiang Rice Variety Certificate 2010015, rice 'Yongyou 12' is a late three-line indica-japonica hybrid cultivar. The cultivar has the following traits: thick and strong stem, high lodging resistance, highly photoperiodic sensitive, long growth season, medium tillering capacity, large panicles with many grains per panicle, high yielding ability, medium-grain-quality, moderate resistance to rice blast disease (Magnaporthe grisea) and rice stripe virus disease, moderate susceptibility to rice bacterial leaf blight (Xanthomonas oryzae), and susceptible to brown planthopper (Nilaparvata lugens).

The cultivar is recommended in the area South of Qiantang River in Zhejiang Province. In this study, the rotating regression design was used to set up a field experiment to evaluate effects of three agronomic factors on hybrid rice 'Youngyou 12' which was planted as a single-season late rice cultivar. Mathematical models were constructed and optimal agronomic schemes were identified.

1 Materials and methods

Rice 'Yongyou 12' was the cultivar, and seedling age (x_1, days), transplanting density (x_2, clusters/ hm2) and net nitrogen ratio (x_3, kg/ hm2) were the decision variables. The experimental design for field condition parameter test was a quadratic regression orthogonal rotational combing design with three factors [8,9, 10]. Treatment levels and experimental layout for the three agronomic factors (i.e., the three decision variables) and the linear coding were contained in Table .1. Yield (y_1, Kg/hm^2) and net profit (y_2, yuan/hm^2) were assumed as objective function in regression modeling.

Table 1 Decision variables and the treatment levels

Linear coding	Seedling age (x_1, days)	Transplanting density (x_2, cluster/ hm^2)	Net N ratio (x_3, kg / hm^2)
+1	30	202500	201.15
-1	18	127500	51.15
0	24	165000	126.15
+1.682	34	228075	252.3
-1.682	14	101925	0

In Table.1, seeds were sown on May 26th and 30th, June 4th, 10th, and 14th for seedling age groups of 34,30,24,18 and 14 days, respectively. All seedlings were transplanted on June 28th. Each plot had an area of 16 m^2 (3.2m x 5m); a layer of plastic mulch was installed in between plots to prevent unintended fertilizer contamination from adjacent plots. A base fertilizer was applied at a rate of 750kg/ hm^2 of calcium superphosphate and 60kg/ hm^2 of potassium chloride in each plot. The field experiment was conducted in 2011, in Shanjia, Shuzhou county of Taizhou. The whole experimental field with different plots was managed consistently except for the treatment factors.

2 Results and analysis

2.1 Effect of the agronomic factors on yield

Analysis of yields from different treatments of the three agronomic factors generated the following quadratic regression model:

$\hat{y}_1$=11844.75--25.50 x_1+158.40 x_2+835.05 x_3+54.75 x_1^2-83.4 x_2^2-476.25 x_3^2+ 145.35 x_1 x_2+66.6 x_1 x_3-42.9 x_2 x_3, in which the interval constrain is in the range of -1.682≤ x_i ≤1.682， i =1, 2,3.

In this model, x_3 and x_3^2 both were at the extremely significant level, x_2, x_1 x_2 were at a significant level (α=0.25), and the rest of the variables were not significant at the α=0.25 level. To improve the accuracy of model, variables that were not significant (α=0.25) were removed, and a simplified yield regression model was constructed as: $\hat{y}_1$=11844.75+158.40 x_2+835.05 x_3-476.25 x_3^2 +145.35 x_1 x_2, where the interval constrain is in the range of -1.682≤ x_i ≤1.682， i =1, 2, 3. There was an extremely significance level for the simplified model as a whole.

Model analysis showed that among the three agronomic factors, rice yield was affected the most significantly by net nitrogen ratio, followed by transplanting density and the seedling age had the least significant impact. Additionally, due to the interacting effect between variables x_1 x_2, the planting density should be reduced for younger seedling, or vice versa, it should be increased for older seedlings (Table 2).

Table 2 The effect of interaction of seedling age with transplanting density on rice yield

x_1	x_2				
	-1.682	-1.000	0.000	1.000	1.682
1.682	11167.20	11441.85	11844.75	12247.65	12522.30
1.000	11333.85	11541.00	11844.75	12148.50	12355.65
0.000	11578.20	11686.35	11844.75	12003.15	12111.30
-1.000	11822.55	11831.55	11844.75	11857.95	11866.80
-1.682	11989.20	11930.70	11844.75	11758.80	11700.30

2.2 Effect of the agronomic factors on the profit of rice production

In this study, prices for different items were estimated at 2.20 yuan/kg rice grains, 1.50 yuan/thousand seedlings, 2.10 yuan/kg urea, 2.70 yuan/kg potassium chloride, and 0.50 yuan/kg and calcium superphosphate. Only material cost was included in the production cost. The net profit from each experimental plot was converted into profit per hectare. A regression model was generated for the correlation between the three agronomic factors and the profit. After removal of the variables at the non-significant level (α=0.25), a simplified regression model for profit was developed as follows:

$\hat{y}_2$ = 24664.05+292.35 x_2 +1478.55 x_3 -1047.60 x_3^2 +319.65 x_1 x_2, in which the constrain interval is at -1.682≤ x_i ≤1.682, i =1,2,3. Test of the significant difference confirmed that the profit regression model behaved basically the same as the yield model, x_3, x_3^2 both were at the extremely significant level, and x_2、x_1 x_2 at a significant level (α=0.25). Therefore, the regression model for profit was also at the extremely significant level as a whole.

Model analysis found that the effect of the three agronomic factors on profit was very similar to that of yield. Net nitrogen ratio had the greatest effect on rice profit, followed by transplanting density, and the seedling age had the least significant impact. Furthermore, there was a significant impact from the interacting effect from variables of x_1 and x_2 , therefore the transplanting density should be reduced for younger seedlings whereas it should be increased for older seedlings for high profit rice production. Although the interacting effect from x_1 and x_2 would have a similar influence on both yield and profit, the two factors must be adjusted appropriately according to local conditions in any agronomic scheme.

3 Computer simulations for the optimization of agronomic scheme

3.1 Optimization of high yield agronomic schemes

A computer simulation was performed using the yield regression model within the constraint interval of -1.682≤ x_i ≤1.682, to screen for high yield agronomic schemes [9, 10, 11]. From the 125 sets of agronomic schemes, 33 sets were selected to

produce a yield above 12000 Kg/ hm^2 (Table 3). Within 95% confidence intervals, the selected values for x_1, x_2, x_3 were -0.301-0.525（22-27 days), 0.276-1.024（175350-203400 clusters/hm^2) and 0.783-1.143（184.95-211.95 kg/ hm^2), respectively.

Table 3 Computer simulation of the agronomic scheme for high yield rice production

Treatment levels	x_1	Frequency	x_2	Frequency	x_3	Frequency
-1.6818	6	0.1818	3	0.0909	0	0.0000
-1.0000	5	0.1515	3	0.0909	0	0.0000
0.0000	8	0.2424	5	0.1515	6	0.1818
1.0000	7	0.2121	11	0.3333	20	0.6061
1.6818	7	0.2121	11	0.3333	7	0.2121

3.2 **Optimization** of high profit agronomic scheme

Table 4 Computer simulation of agronomic schemes for high profit rice production

Treatment level	x_1	Frequency	x_2	Frequency	x_3	Frequency
-1.6818	6	0.1935	3	0.0968	0	0.0000
-1.0000	5	0.1613	4	0.1290	0	0.0000
0.0000	6	0.1935	5	0.1613	8	0.2581
1.0000	7	0.2258	10	0.3226	19	0.6129
1.6818	7	0.2258	9	0.2903	4	0.1290

Computer simulation of the profit regression model using the constraint intervals of $-1.682 \leq x_i \leq 1.682$, was performed to select for the high efficiency agronomic schemes. From 125 schemes, 31 schemes would produce a profit above 24750 yuan /hm^2 (Table 4), where the selected values for x_1, x_2, x_3 value (within the 95% confidence intervals) were -0.321-0.558 (22-27 days), 0.121-0.917(169545-199395 clusters/hm^2) and 0.641-1.019(174.30-202.65 kg/hm^2), respectively. It can be seen that the effects of the three agronomic factors followed the same trend for improving profit as well as for increasing yield.

4 Conclusion and discussion

In this study, regression mathematical models were constructed to determine the effect of agronomic factors including seedling age, transplanting density and net nitrogen fertilizer rate on the yield and profit of rice ‘Yongyou No. 12’. An optimized agronomic scheme was developed for single-cropping of the late hybrid rice cultivar. The three agronomic factors affected yield or net profit of rice production in a similar manner. Among the three factors, net nitrogen ratio had the greatest effect on yield and net profit, followed by transplanting density, and seedling age had the least significant effect. By using modeling analysis in combination with the real field condition, the optimized agronomic scheme for the highest yield and highest profit for rice ‘Yongyou No. 12’ was projected to use seedlings of the 22-25 days old, at a transplanting density of c.a.172500 clusters/hm2 (no less than 165000 clusters/hm2), and using a net nitrogen ratio at 180-195kg/hm2 when growing the crop under the same field conditions used in this study.

However, all the single-cropping late rice farms had higher yield in 2011 compared to previous years, which led to a higher projected yield and net profit increases in the optimized agronomic scheme developed in this study. It remains to be tested if such high yield and profit will be stably achieved in future years.

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