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A Mathematical Optimization Model of Cultural Factors for High-Yield and High-Profit Production of Sweet Potato "Xinxiang"

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Abstract. In this study, an experiment was performed to determine the effect of three cultural factors including planting density and levels of urea and potassium sulphate on the yield and profit of sweet potato 'Xinxiang'. The field experiment was designed according to a simplex lattice method. A regression mathematical model was constructed based on the correlation between the three test cultural factors and the yield and profit of fresh sweet potato. The model determined that for sweet potato 'Xinxiang' to produce the highest yield and profit, the planting density should be 49500-54000 plants /hm^2, and fertilizers should be applied at rates of 225 kg/ hm^2 of urea fertilizer, and 195-270 kg/ hm^2 of potassium sulphate if the soil condition is the same as in this experiment.

Keywords: Sweet potato 'Xinxiang', simplex lattice design, cutting density, fertilizer, mathematical model, optimization

1.Introduction

Sweet potato is an agronomic crop producing high and stably yield of tubers that are very nutritious and have multiple other uses. Sweet potato tubers can be eaten as a staple food, or they are also used for animal feeds or as industrial raw materials. Because of the high yield, growing sweet potato can efficiently increase total agricultural productivity. Increased sweet potato cultivation is motivated by the development of processed products from sweet potato tubers, which in turn promotes animal husbandry, animal feed processing business, and food, pharmaceutical and chemical industries. Sweet potato tuners contain vitamins, polysaccharides, fiber, collagen and steroids. Rational use of sweet potato in the meals can improve is the health of consumers.

In recent year, the selection and utilization of 'Mini' sweet potato has made significant progress. The tubers weigh 50-150 g, they are shot-cylindrical shaped and in very uniform sizes. The flesh of the tubers has a red or yellow color, tender texture, and rich flavor. The oven dry weight ratio of the tubers is 25%-29% of total fresh weight. Plants have an early maturity, and the marketable ratio of tubers is 75%-85%. Tubers are set in shallow depth of soil and they also form clusters, which is more convenient for machine harvest.

The min sweet potato is suitable for modern small-sized family. They can be cooked using microwave-steaming or boiling. It is an ingredient for a good meal with a mix of coarse- and fine- textured foods have a good mix in a diet.

In big cities like Shanghai, Hangzhou and Nanjing, the price of mini sweet potato is 3-5 times higher than the regular cultivars in small and large grocery shops. Consumers seem really like the goods.

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Presently in China, sweet potato 'Xinxiang' is the dominant cultivar for mini sweet potato [1]. Plants are semi-erect with short branches growing on a 1.55 m-long main vane. Stems are green and of medium thickness. Each cutting will form 10 branches. Leaves are heart shaped, with green leaf tip, the leaf veins are green but the leaf base has a purple color. The apex of the apical bud is obtuse, and there are very few flower buds.

Tubers normally set in the shallow depth of soil and grow in cluster. The sizes of the tubers are uniform. The purple red skinned potatoes bear very few invisible bud eyes. Tubers are elongate-cylindrical shaped. Each plant bears 6.4-8.2 tubers.

In addition to the early maturity, the uniform-sized tubers with a high marketable rate, the cultivar has been highly recommended for commercial production.

This study was conducted to explore the best strategy to achieve high yield and high profit for this cultivar by optimizing cultural factors such as planting density and fertilizers.

2. Experimental design

Experimental design was a simplex-lattice design mixture tests design, [2,3]. The three testing factors were the density of plants (x_1, plants/ hm^2), the amount of urea (x_2 ,kg/ hm^2), and rate of potassium sulphate (x_3, kg/ hm^2). The P (3, 2) design method was used for the experiment layout in the field (Table 1). The objective functions were fresh weight (y_1, kg/ hm^2), and net profit (y_2 , yuan/ hm^2) of tubers.

Table. 1 Experimental design

Treatment	Component factor value Simplex lattice design			Experimental factor value		
	x_1	x_2	x_3	x_1 （plants / hm^2）	x_2 （kg/ hm^2）	x_3 （kg/ hm^2）
1	1.00	0.00	0.00	69000	150	0
2	0.00	1.00	0.00	36000	510	0
3	0.00	0.00	1.00	36000	150	600
4	0.50	0.50	0.00	52500	330	0
5	0.50	0.00	0.50	52500	150	300
6	0.00	0.50	0.50	36000	330	300

A base fertilizer of 300 kg/ hm^2 calcium superphosphate containing 160g/ kg P_2O_5 active gradient was used in all the plots. Potassium sulphate with active gradient of K_2O at 500 g/ kg was also applied as a base fertilizer. Urea fertilizer was applied in three times as the (A) transplanting liquid fertilizer, (B) 30d post-transplanting, and (C) 60-65d post-transplanting. The 150 kg/ hm^2 treatment was divided among the three times applications as "60:90:0; A/B/C " kg/ hm^2, the 330 kg/ hm^2 treatment was divided as "60+180+90; A/B/C" kg/ hm^2, and the 510 kg/ hm^2 treatment was divided as: "60+300+150; A/B/C" kg/ hm^2. The nitrogen content in urea was 460 g/ kg.

The experiment was performed in Linhai, Zhejiang. Soil of the experiment field was mire sandy soil, it contained 8.16 g/ kg of organic matter, 53.8 mg/kg of available nitrogen, 49.9 mg/kg of P, 83.8mg/kg of K. Soil pH was 5.38.

According to the experimental design, the experiment field was divided into 6 plots each having a land area of 20.0 m^2. The row-row distance of sweet potato plants was 0.75 m^2. The cuttings were transplanted on June 27, 2006, and the crop was harvested on Nov. 11. The whole growing season was 137d. Protection rows were designed on the four sides of the field. All the plots were managed uniformly.

3. Results and Analysis

3.1 Sweet Potato Yield

Tuber yield was converted into kg per hectare, which was 45914.85, 38804.70, 38009.25, 42846.75, 54484.80, 41657.10 kg/ hm^2 in plots 1, 2, 3, 4, 5 and 6, respectively. Then the P (3, 2) parameter estimation was done using the following formula[2,4]:

$b_i = y_i$

$b_{ij} = 4 y_{ij} - 2(y_i + y_j)$ ($i < j$, $i, j = 1, 2 \ldots\ldots p$).

The regression model for prediction of fresh sweet potato yield using the data of density of plants, and the amounts of urea and potassium sulphate fertilizers was:

$\hat{y}_1 = 45914.85 x_1 + 38804.70 x_2 + 38009.25 x_3 + 1947.90 x_1 x_2 + 50091.00 x_1 x_3 + 13000.50 x_2 x_3$.

When the six treatment combination code values (x_1, x_2, x_3) were introduced into the regression model, the predicted yield matched the one from the experimental field. Then in the x^2 test, there was no significant difference between the predicted and experimental yields. Since the experiment was a saturated design, the theoretical value should match the actual measurement. Therefore, the regression model simulated the real situation.

Then a step index of 0.1 was applied to the three factors in the model, x_1, x_2, x_3, to optimize computer simulating selection[5,6,7] while satisfying the specified condition of $\sum x_i = 1$. There were 66 combinations of three factors. When the fresh sweet potato objective yield was set at above 46500 kg / hm^2, 28 of the 66 combination should be able to reach the objected yield. When average value of x_1, x_2, x_3 was at 0.475, 0.150, and 0.375 (P= 95%), the range of the value was 0.3970-0.5530, 0.0999-0.2001, and 0.2970-0.4530 for x_1, x_2, x_3. The corresponding cultural factor combination was: planting density at 49095-54255 plants/ hm^2, urea at 185.00-222.00 kg/ hm^2, and potassium sulphate at 178.20-271.80 kg/ hm^2.

3.2 Sweet Potato Profit

In the simulation process, the price for fresh sweet potato, cuttings, urea, and potassium sulphate and calcium superphosphate price was 0.60 Yuan/kg, 3.00 yuan/100 plants, 1.70 Yuan /kg, 2.00 Yuan/kg and 0.46 Yuan/kg, respectively. The net profit was calculated as Yuan/ hm^2. The net profit for plot 1-6 was 25085.85, 21197.85, 20132.55, 23434.05, 30122.85, and 22615.20 yuan/ hm^2, respectively.

Similarly, the net profit data were used to develop the regression mathematical model, which was:

$\hat{y}_2 = 25085.85 x_1 + 21197.85 x_2 + 20132.55 x_3 + 1168.80 x_1 x_2 + 30054.60 x_1 x_3 + 7800.00 x_2 x_3$.

The x^2 test confirmed that the regression model can simulate the real situation. Then the net profit of 25800 Yuan / hm^2 was selected as objective function to screen the 66 cultural combinations. Out of all the combinations, 25 met all the criteria. The values for x_1, x_2, x_3 were near those for the yield model when it was objected at 46500 kg / hm^2.

When the average value of x_1, x_2, x_3 was set at 0.4840, 0.1280, 0.3880 (P=95%) the range of the three parameters was 0.4000-0.5680, 0.0796-0.1764, 0.3052-0.4708, respectively. The optimal cultural combination was: planting density of 49200-54750 plants / hm^2, urea at 178.65-213.45 kg/ hm^2, and potassium sulphate at 183.15-282.45 kg/ hm^2.

3.3 Conjoint Analysis of Yield and Profit

When using the $\hat{y}_1$ and $\hat{y}_2$ regression mathematical models and meanwhile satisfying the criteria of minimum yield of 46500 kg/ hm^2, and net profit at 25800 Yuan/ hm^2, to screen the cultural factor combinations. There were 25 combinations that met those requirements, furthermore the optimized combination was the same as the one for net profit. These results confirmed that the same cultural plan can be used to increase yield and profit at the same time.

4. Conclusion

In this study, three main cultural factors affecting the yield and quality of sweet potato were investigated, including the density of plants, the schedule of urea fertilizer application and the rate of potassium sulphate fertilizer. Using data collected from the field, a regression model was developed for the correlation between the three cultural factors and yield. Further interpretation of the model in combination with the market prices of fertilizer and fresh sweet potato price, has determined that to achieve the highest yield and profit for sweet potato ‘Fragrance Heart’ the best cultivation plan should be using plant density of 49500-54000 plants/ hm2, 225 kg/ hm2 urea , and 195-270 kg/ hm2 potassium sulphate.

The simplex-lattice design is a saturation experimental design method[8], where each $M\{p,m\}$ contain design points equal to the number of unknown parameters from the response function. Therefore each factor in the experiment has to be executed as accurate as possible, in order to produce data that can be used to develop a model that will simulate the real situation with high accuracy.

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