FERTILIZATION MODEL FOR FLUE-CURED TOBACCO (*NICOTIANA TABACUM* L.) IN SOUTHWEST CHINA

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Abstract. The fertilization model is an important breakthrough in the field of nutrient management for high quality crop production. However, there are few studies on the flue-cured tobacco fertilization model. In this study eight plots were selected, for use in a fertilization experiment to determine the optimal nitrogen, phosphorus and potassium fertilizer application amounts for flue-cured tobacco planting in the Southwest China. Based on parameters such as the nutrient requirements, fertilizer utilization rate, and soil nutrient correction coefficient of flue-cured tobacco, the curves of N, P_2O_5, K_2O and their corresponding nutrient correction coefficients were constructed. We fitted a non-linear curve model using soil parameters, i.e. yield per area, nutrient requirements and fertilizer utilization rate, etc. The result showed that the recommended fertilization models are $N = 0.091 \times Y - 149.505 \times S_N^{0.029}$; $P_2O_5 = 0.072 \times Y - 11.595 \times S_P^{0.749}$; $K_2O = 0.199 \times Y - 55.924 \times S_K^{0.351}$. The validation of the experiments showed that the yield of the flue-cured tobacco reached about 2,700 kg ha^{-1}. In addition, the recommended amount of fertilization was 30% less than the conventional fertilizer application. Therefore, the recommended amount will lower the production cost, reduce the environmental pollution caused by excess soil fertility, and promote the sustainable development of flue-cured tobacco planting.
Keywords: *soil nutrients, fertilizer utilization rate, yield, recommended fertilization, decision model*

Introduction

Plant nutrients are the major components of crop growth, of which nitrogen (N), phosphorus (P) and potassium (K) are considered the most basic elements for agricultural production. Thus, the maintenance of soil fertility is needed for crop productivity (Shen et al., 2010; Yavitt et al., 2011). The reasonable application of nitrogen phosphorus and potassium fertilizers provides the important contribution to increasing yield. To obtain the highest yield, farmers usually use excessive fertilization regardless of the environmental impact (Zhao et al., 2016; Williams et al., 2017). Excess fertilizer will be lost to the environment in various ways, including surface runoff, underground leaching and trace gas emission, causing considerable environmental problems (Pappa et al., 2011; Ahmed et al., 2017; Russo et al., 2017).

An increasing body of evidence based on long-term experiments have shown that environmental pollution from agricultural production caused by excessive fertilization use can be alleviated by changing tillage methods and crop rotation systems (Lehmeier et al., 2013; Sun et al., 2015; Guillaume et al., 2016), as well as by modifying the

fertilization method and irrigation systems. Gilhespy et al. (2014) showed that different fertilization methods and fertilizer application amounts could change the nitrogen load of paddy fields. Hossain et al. (2018) noted that an appropriate fertilizer-water ratio can improve the physicochemical properties of the soil and increase cucumber yields.

Recently, scientists have conducted many targeted works on nitrogen phosphorus and potassium fertilizers (Subhashini, 2016; Kumaresan et al., 2019; Lisuma et al., 2020). Although most studies provide valuable perspectives on crop growth and development, the conclusions and recommendations obtained have some limitations. For example, the short length of the experimental period limited the possibility of obtaining robust conclusions, making difficult the establishment of appropriate cropping strategies with only few years of experimental data. Thus, strong recommendations for crop management would require a large number of experimental years with time and cost associated. Therefore, the combination of experimental work with the use of crop simulation models may help to overtake this limitation.

Flue-cured tobacco (*Nicotiana tobacum* L.) is an important cash crop in China. Many applications of flue-cured tobacco in drug resources and food development is being continuously discovered and utilized (Sheets et al., 2016; Crossthwaite et al., 2017). Therefore, high-quality flue-cured tobacco planting has broad prospects (Vann et al., 2013; Amankwa et al., 2014; Shen et al., 2017). The estimate of reasonable amounts of fertilization by constructing a flue-cured tobacco fertilization model through different fertilizing experiments is an important breakthrough in high-quality flue-cured tobacco production (Hu et al., 2018). At present, few studies have reported on flue-cured tobacco fertilization models, and most studies did not use factors such as flue-cured tobacco quality to verify the fertilization models in field experiments.

This study performed fertilization experiments on flue-cured tobacco in a mountainous area of Southwest China. And this study had two main objectives: (1) to determine a rational fertilization amount in flue-cured tobacco planting; (2) to establish fertilization model for flue-cured tobacco and to verify the model.

Materials and methods

Materials

Site description

From 2013 to 2017, eight experimental plots (1-8) in mountainous areas of southwest China were selected for field experiments. In 2018, three representative tobacco plots (I, II, III,) were selected to conduct validation experiments. These plots are located in the Experimental Station of the Yanbian County, Panzhihua City, Sichuan Province (27°05′N and 101°46′E, 2097 m above sea level) (*Figure 1*).

Our study area belongs to the subtropical dry-hot valley climate, and shows mean annual precipitation of 1065 mm, which is mainly concentrated between June and October. The annual average sunshine duration is 2307 h, and the annual average temperature is 19.2 °C (Li et al., 2018). The soils are Alumi-Ferric Alisols (FAO/UNESCO, 1988). Every experimental plot is flat and inside with uniform fertility. The basic physicochemical properties of the surface soil (0-20 cm) were measured before the experiment in 2013 (*Table 1*).
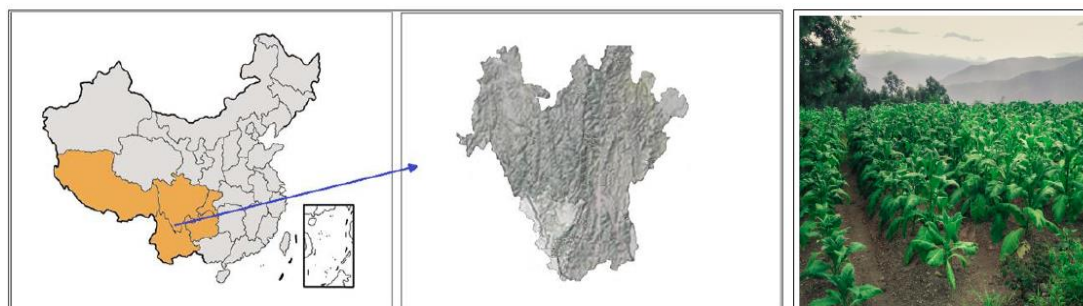
Figure 1. *Map of the experimental field in southwest China*

Table 1. *Initial soil properties of the experiment in Yanbian County during 2013, southwest China*

Experimental plots	pH	SOC g kg^{-1}	Total N g kg^{-1}	Alkali-N mg kg^{-1}	Olsen-P mg kg^{-1}	Ava-K mg kg^{-1}
1	6.15	28	1.33	83.5	2.2	142.5
2	5.85	31.8	1.62	115.35	8.35	135.62
3	6.51	9.58	0.85	86.7	8.53	105.28
4	6.48	25.85	1.25	95.36	2.05	138.85
5	6.52	14.35	0.92	78.35	10.38	102.35
6	5.72	23.35	1.38	125.32	11.24	125.18
7	6.65	13.25	1.32	92.35	12.55	123.75
8	6.25	25.55	1.68	118.34	8.48	135.65

SOC was soil organic carbon, Total N was total nitrogen, Alkali-N was alkali-hydrolyzale nitrogen, Olsen-P was Olsen phosphorus, Ava-K was available potassium

Experimental design

Seven treatments were conducted using a randomized block design with three replicates. All treatments were applied in every experimental plot (*Table 2*). The plot size was 77 m^2 (11 m x 7 m). The fertilizer used for the test was calcium ammonium nitrate for agricultural use (N content: 155 g kg^{-1}), superphosphate (P$_2$O$_5$ content: 160 g kg^{-1}) and potassium sulphate (K$_2$O content: 500 g kg^{-1}), of which 70% was basal fertilizer (applied at the transplanting period), and 30% was topdressing (applied 20 days after transplanting). The flue-cured tobacco variety used in the experiment was Yunyan87, which was provided by the China Tobacco Import and Export Sichuan Co. Ltd.

Table 2. *Application scheme of flue-cured tobacco fertilizer (kg ha^{-1})*

Treatments	N	P$_2$O$_5$	K$_2$O
1	0	0	0
2	0	135	270
3	90	0	270
4	90	135	0
5	60	90	180
6	90	135	270
7	120	240	360

The experimental flue-cured tobacco was planted with floating seedlings that were transplanted on April 20th of each year, harvest and baking began on July 20, and the harvest ended on September 1st. The field growth period was 130 days, and the management methods for the field tillage were conducted according to the local conventional methods. The experimental plots were ploughed after 15 and 35 days of flue-cured tobacco transplanting, and irrigated when the soil moisture content is less than 60%. When the buds of flue-cured tobacco grow to 4-6 cm, remove the buds and the next 3 leaves. Tobacco leaves were harvested in different plots and uniformly baked before the yield was calculated. Central leaves (2 kg) with consistent maturity (at leaf positions 8, 9, 10 and 11) were selected from each treatment for the chemical composition analysis. The quality of flue-cured tobacco was evaluated by chemical composition content.

*Evaluation criteria for high-quality flue-cured tobacco*

Usually we use the content of chemical composition as the evaluation standard of flue-cured tobacco quality (White et al., 1979). A review of multiple sources of reference data showed that in high-quality flue-cured tobacco leaves, the nitrogen content is 2.5%; the phosphorus content is 0.6%; the higher the potassium content is, the better; the total sugar content is 20%; the reducing sugar content is 15%; the chlorine content is 0.5%; and the nicotine content is 2% (Sun et al., 2011).

Methods

The model was developed using Truog-Stanford equation of the nutrient balance method. The equation was that calculated the difference between the amount of fertilizer required by the crop and the amount of fertilizer provided by the soil, and then determined the amount of fertilizer applied to the crop. The core idea is that the nutrients plants need to grow are provided by both soil and fertilizer. Fertilizing is used to supplement the soil nutrient deficiency during crop growth. Only when the nutrient supply and demand balance is reached can the crop achieve the target yield. Therefore, the Truog-Stanford equation mainly involves parameters such as target yield, crops required fertilizer amount, soil fertilizer supply amount, and fertilizer utilization rate. First, the physicochemical properties of the soil had to be accurately measured. The required pattern for the crop fertilizer and the annual yield had to be determined. Then, field experiments were conducted to determine the target yield and determine the type, quantity and ratio of the fertilizer required for the target yield.

Determination of fertilizer utilization rate

The amount of N, P_2O_5, and K_2O uptake by flue-cured tobacco in yield per unit area was calculated based on analysis in the field experimental tests of eight experimental tobacco plots and laboratory tests from 2013 to 2017 (*Figure 2A*). The N, P_2O_5 and K_2O fertilizer utilization rates of the 8 experimental plots were calculated according to *Equation 1* (*Figure 2B*). It shows that the average N utilization rate was 38.21%, and its value varied from 31.95% to 45.33%; the average phosphorus (P_2O_5) utilization was 15.58%, with values ranging from 11.87% to 19.82%; and the average potassium (K_2O) utilization rate was 28.28%, with its value varying in the range of 20.65% to 34.53%.
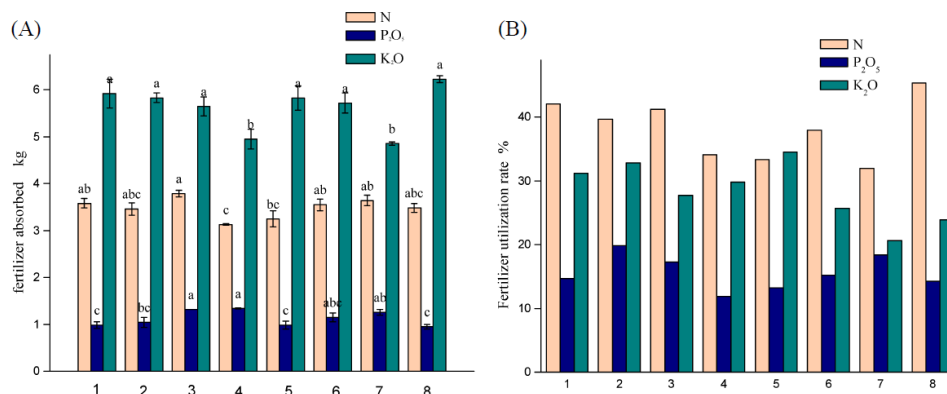
Figure 2. *The amount of N, P₂O₅ and K₂O fertilizer absorbed by per 100 kg flue-cured tobacco (A) and the fertilizer utilization rate of each experimental plot (B). Different letters within the same column indicated significant differences (p < 0.05)*

$$R = \frac{A_1 - A_0}{F} * 100\%$$ (Eq.1)

where, R represents the fertilizer utilization rate; A1 is the fertilizer absorption amount in fertilization area, and A0 is the fertilizer absorption amount in 0 fertilization area; F represents the fertilizer application amount in the experiment.

Calculate the soil fertility correction coefficient

The soil fertility correction coefficient for each experimental plot was calculated according to *Equation 2*. It shows that the correction coefficients of the soil Alkali-N, Olsen-P and Ava-K varied significantly, mainly relative to factors such as the soil available nutrient content, soil moisture status, soil types, climatic conditions and growth conditions of the flue-cured tobacco (*Figure 3*). The correction coefficients for the Alkali-N ranged from 22.25% to 37.68% with an average of 29.98%; the correction coefficients for the Olsen-P varied from 35.96% to 67.39% with an average of 50.57%; and the correction coefficient for the Ava-K ranged from 27.68% to 35.95%, with an average of 31.46%.
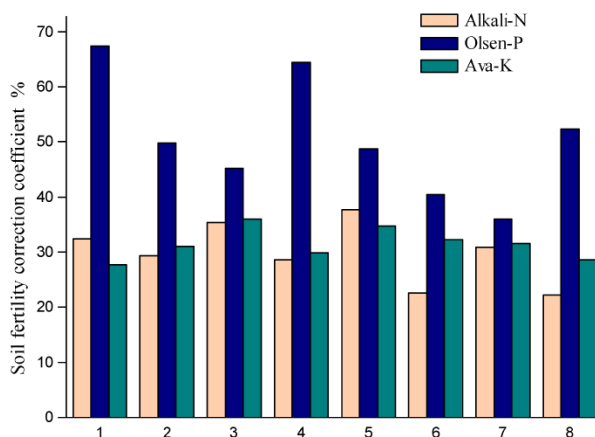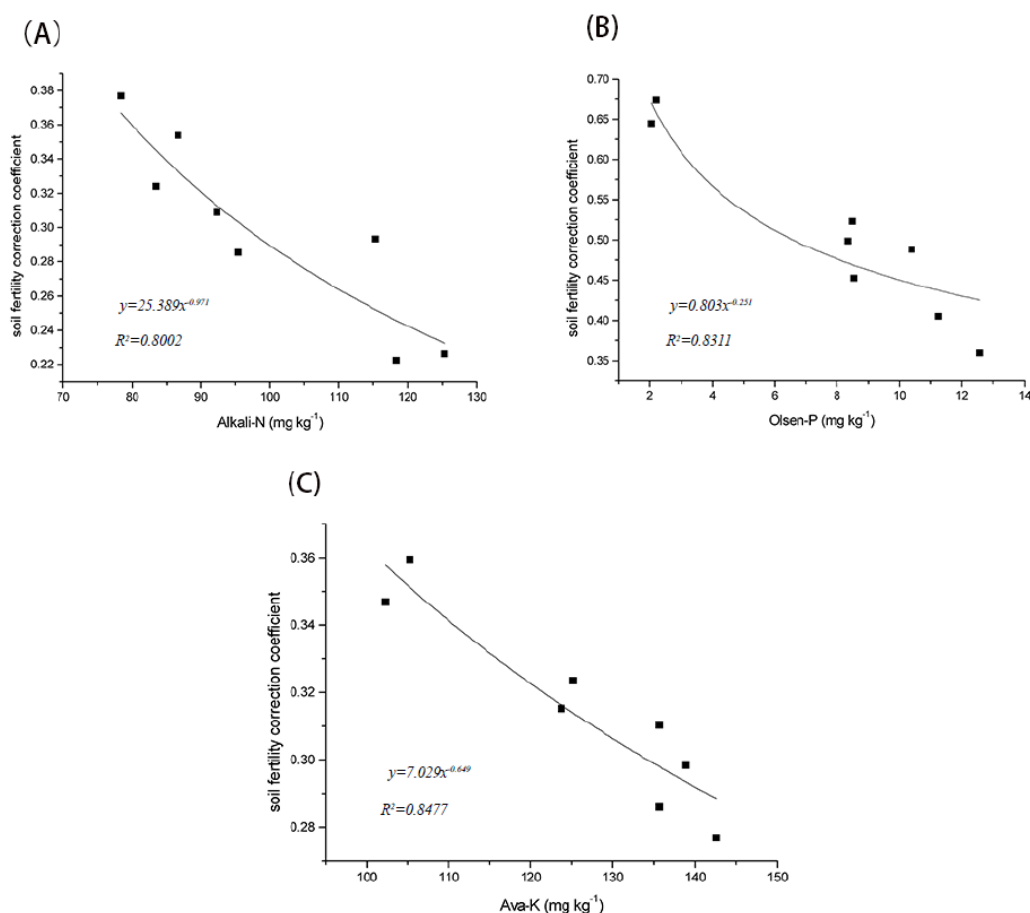

Figure 3. *Soil fertility correction coefficient (B) of each experimental plot*

$$C = \frac{A_0}{S*0.15} * 100\% \qquad \text{(Eq.2)}$$

where, C represents the soil fertility correction coefficient. S represents the soil fertility. 0.15 is the conversion factor of the measured value (mg kg^{-1}) of soil fertility to the potential fertilizer supply amount per hectare of arable soil.

Construction of the recommended fertilization model for flue-cured tobacco

In this study, we used the soil available fertility content (x, mg kg^{-1}) and the corresponding soil fertility correction coefficient (y) for regression analysis and model fitting to establish the regression equations (*Figure 4*). As can be seen in *Figure 4*, with the increase in the Alkali-N, Olsen-P and Ava-K concentrations in the experimental plots, the corresponding correction coefficients all showed a downward trend. The fitting was performed using a Curve model, and the F test showed that all regression relationships achieved significant levels (p <0.05).

Figure 4. *Curve fitting model of Alkali-N (A), Olsen-P (B), Ava-K (C) and soil fertility correction coefficient*

The recommended fertilization model of flue-cured tobacco for nitrogen (N), phosphorus (P$_2$O$_5$), and potassium (K$_2$O) fertilizers with different target yields was obtained using the Truog-Stanford *Equation 3*.

$$\text{Fertilizer application(pure nutrient)} =$$

$$= \frac{\text{Fertilizer requirement - Soil fertility supply}}{\text{Fertilizer utilization rate}} = \frac{Y * U - S * 0.15 * C}{R} \qquad (Eq.3)$$

where: Y represents the target yield, and U stands for the required fertilizer in yield per unit area.

Based on the physicochemical properties of the soil, combined with the soil fertility correction coefficient, nutrient uptake by flue-cured tobacco, fertilizer utilization, etc., the fertilization models were as followed:

$$N = 0.091 \times Y - 149.505 \times S_N{}^{0.029}$$
$$P_2O_5 = 0.072 \times Y - 11.595 \times S_P{}^{0.749}$$
$$K_2O = 0.199 \times Y - 55.924 \times S_K{}^{0.351}$$

In the above three models, N, P_2O_5, and K_2O, were the recommended amounts of the nitrogen phosphorus and potassium (pure nutrients) fertilization. *Y* was the target yield, and *SN*, *SP* and *SK*, were the contents of the Alkali-N, Olsen-P, and Ava-K in the soil.

Result and Discussion

Validation the fertilization model

In 2018, the verification experiments were conducted in Yanbian County, Panzhihua City. According to the yield and quality conditions of flue-cured tobacco in Panzhihua City over the years, combined with relevant literature and consultation with relevant experts, the target yield of flue-cured tobacco was set at 2,700 kg ha^{-1}. Based on the studied fertilization models for recommended nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) fertilization, the recommended fertilization amount at each verification plot was calculated (*Table 3*).

Table 3. Fertilization verification experiment of flue-cured tobacco in 2018

Verification plot	Original soil-fertility (mg kg⁻¹)			The model recommended fertilizer application (kg ha⁻¹)		
	Alkali-N	Olsen-P	Ava-K	N	P_2O_5	K_2O
I	125.83	9.31	128.06	73.69	132.74	230.18
II	72.95	16.27	82.75	76.39	100.73	273.82
III	118.37	2.53	185.5	74.00	171.16	187.52

In this study, we selected 2 kg of central leaves with consistent maturity from the three validation plots for each chemical composition analysis. The chemical composition and yield of flue-cured tobacco from the three verification plots are shown in *Table 4*. It shows the chemical component contents of the flue-cured tobacco from each plot were consistent with those of high-quality flue-cured tobacco, and the yield reached the expected target approximately 2,700 kg ha^{-1}. The recommended amount of fertilization was 30% less than that of the conventional fertilizer application. Therefore, in the verification plot, the application of N was 74.00-76.39 kg ha^{-1}, the application of P_2O_5 was 100.73-171.16 kg·ha^{-1}, and the application of K_2O was 187.52-273.82 kg·ha^{-1}. The recommended fertilization model is reasonable and feasible for the experimental area.

Table 4. *The chemical composition and yield of flue-cured tobacco from the verification plots*

Verification plot	Nitrogen	Phosphorus	Potassium	Total sugar	Reducing sugar	Chlorine	Nicotine	Yield
	%	%	%	%	%	%	%	kg ha^{-1}
I	2.03	0.64	2.36	19.2	14.71	0.41	1.82	2805.5
II	2.11	0.52	2.28	18.87	14.15	0.53	1.95	2630.3
III	1.96	0.48	2.45	21.03	15.32	0.48	2.17	2735.5

Effect analysis of the fertilization model

Studies have shown that crop yield and quality vary with different apply of fertilization (Wang et al., 2015). In recent years, in order to obtain higher yield, farmers usually apply excessive fertilizer, and the phenomenon of blind overfertilization is quite common. For instance, the current N fertilization rate for paddy fields of China is approximately 300 kg ha^{-1}, which exceeds the actual demand of rice growth (Chen et al., 2011; Xia and Yan, 2012). In most areas of China, the application of nitrogen and phosphate were too high, which affects the absorption of other nutrients (Zhang et al., 2010). The excess fertilizers will be lost to the surroundings through different pathways, including surface runoff, subsurface leaching and trace gas emissions, causing considerable environmental issues (Zhao et al., 2016).

Scientists have been actively searching for the best fertilization plan to promote continuous improvement of crop yield and quality. The fertilization model is one of the main methods of precision fertilization. Currently, the construction of a fertilization model mainly adopts a regression function model (Thompson et al., 2015), comprehensive fertilization models (Basso et al., 2016), and artificial neural network models (Alvarez and Steinbach, 2017). Each of the above methods has advantages but also has limitations. The regression function method determines the functional relationship between fertilization and yield or quality and usually does not consider the effect of basic soil fertility. The comprehensive fertilization model uses orthogonal design and orthogonal trends to analyse the fertilizer effect while the largest experimental workload used, and the error is difficult to control. The artificial neural network model requires a relatively large database, and the modelling cost is relatively high.

This study is a fertilization model based on the Truog-Stanford equation of the nutrient balance method. The fertilization amount of flue-cured tobacco recommended by this model is simple and effective. The yield of flue-cured tobacco was estimated in advance, and the best amount of fertilizer was calculated according to the fertilizer utilization rate and soil fertility correction coefficient. Sharma and Singh (2000) suggested that fertilizer recommendations based on targeted yield concept were more balanced, profitable and helpful in controlling soil nutrient mining and was essential for sustainable crop production. The verification tests showed that the model can help improving the formulation, balanced fertilizer management strategies in flued-cured tobacco. Such fertilizer management strategy will be more advantageous compared to conventional blanket and imbalanced fertilizer recommendation.

In this study, the amount of fertilizer recommended by the model was 30% less than the amount of conventional fertilization. In flue-cured tobacco planting, the application amount of N, P$_2$O$_5$, and K$_2$O fertilizer recommended by the model can decrease the input of fertilizer, reduce the production cost, and farmers can harvest more tobacco

with less input. In addition, reducing the application of N, P_2O_5, and K_2O fertilizer can alleviate the soil pollution caused by excessive fertilization, and maintain the sustainable development of agricultural production. Therefore, the fertilization model obtained in this study plays a promoting role in flue-cured tobacco planting and can keep the health of ecological environment.

Conclusion

In this study, eight representative tobacco plots were selected in the mountainous area of southwest China for field experiments. Based on the Truog-Stanford equation of the nutrient balance method, the recommended flue-cured tobacco fertilization model was constructed. The fertilization models are $N = 0.091 \times Y - 149.505 \times S_N^{0.029}$; $P_2O_5 = 0.072 \times Y - 11.595 \times S_P^{0.749}$; $K_2O = 0.199 \times Y - 55.924 \times S_K^{0.351}$. The recommended fertilizer amount by the model was 30% less than the amount of conventional fertilization, and the model was reasonably feasible in the experimental area. The model in this study was closely related to the varieties of flue-cured tobacco and the basic soil fertility of the experimental plot. The verification and improvement of the model in more areas will be the focus of future studies.

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