Comprehensive Evaluation of Tobacco-Growing Soil Fertility in Typical Tobacco-Growing Areas of Yunnan

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Abstract. Soil fertility is a determinant factor for tobacco yield and quality. As a premier tobacco-producing region in China, Malong County of Qujing Municipality necessitates continuous soil fertility monitoring and adaptive fertilization management. This study conducted a comprehensive fertility assessment by analyzing pH, organic matter (OM), total nitrogen (TN), total phosphorus (TP), total potassium (TK), available phosphorus (AP), and available potassium (AK) in tobacco-cultivated soils. The results demonstrated generally appropriate levels of OM, TN and TP, with abundant AK content (32.26% of soils showing exceptionally high levels) - conditions favorable for tobacco cultivation. Compared with 2023, both soil pH and nutrient contents increased in 2024. The proportion of soils suitable for tobacco growth, with pH values suitable for tobacco growth, OM content, TN content, and TP content, increased to 22.58%, 51.61%, 54.84%, and 58.06% respectively; the proportion of soils with extremely high AK content increased to 32.26%. The TK and AP contents of most soils were at a relatively low level. The integrated fertility evaluation indicated 64.51% of soils reached Grade I-II quality in 2024, confirming an overall medium-to-high fertility status. Compared with 2023, the soil nutrient condition in 2024 has improved. However, the problems of soil acidification and low TK and AP content remain prominent. Measures such as adding lime and biochar need to be taken to improve the soil and enhance the yield and quality of tobacco.

Keywords: tobacco-growing areas; soil fertility; tobacco; comprehensive evaluation

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1 Introduction

Flue-cured tobacco is one of the most important economic crops worldwide, and China holds a dominant position in global tobacco production, with its output accounting for more than one-third of the global total [1, 2]. Yunnan is the largest province in tobacco production in China, and tobacco planting is the economic pillar of its agricultural production [3]. Healthy and suitable soil is the basis for producing high-quality tobacco. During agricultural production, unreasonable farming and fertilization methods lead to a decline in soil quality [4]. The fertility status of tobacco-growing soil directly affects the growth and development of tobacco, determining its quality and yield. As an important tobacco producing area, Malong County, Qujing City, its soil fertility status directly affects tobacco planting. Therefore, this study selected Ma Long County as the research object and conducted a comprehensive evaluation of soil fertility.

Soil fertility is mainly determined by various nutrient indicators, including soil pH, organic matter, total nitrogen, total phosphorus, total potassium, available phosphorus and available potassium, etc. Studies have shown that soil pH is closely related to the formation of carbohydrates and high-quality components in tobacco leaves. Overacidity of soil will reduce soil nutrient availability and reduce nutrient utilization efficiency of tobacco [5, 6]. In addition, growing tobacco in acidified soil will exacerbate the emission of nitrogen oxides [7]. Sufficient carbon and nitrogen reserves in the soil can enhance the diversity and abundance of bacteria, thereby increasing the yield and quality of tobacco [8]. Research by Huang Shihang found that organic matter in tobacco-growing soil was significantly negatively correlated with potassium content in tobacco leaves, and significantly positively correlated with nicotine content [9]. It has been found that soil nitrogen deficiency can lead to slow growth of tobacco and low nicotine content in tobacco leaves. Excessive nitrogen will lead to excessive growth of flue-cured tobacco, late maturity, high nicotine content, poor aroma quality, affecting the quality and taste of tobacco leaves [10, 11]. Studies have shown that the tobacco output value increases first and then decreases with the increase of nitrogen application, and increases with the increase of phosphorus and potassium application [10]. Nghiem [12] found that the fresh and dry yields of tobacco were significantly positively correlated with the available nitrogen and phosphorus contents in the soil. Therefore, it is not the case that the higher the content of each nutrient indicator, the better. A classification discussion is necessary.

A single nutrient indicator cannot comprehensively and accurately reflect the nutrient status of tobacco-growing soil. Therefore, previous studies have explored many different comprehensive evaluation methods [13]. In this study, the physical and chemical properties of tobacco-growing soil in Malong County, Qujing City were analyzed. Based on the fuzzy mathematical model, the integrated fertility index (IFI) was used to evaluate the soil fertility of tobacco-growing soil in this area, in order to provide a scientific basis for rational fertilization and soil conservation measures for tobacco production in Malong County.

2 Materials and Methods

2.1 Soil Sample Collection from Tobacco-growing Areas

Tobacco fields were selected in the main tobacco-growing area of Malong County, Qujing City, and 31 soil samples were collected in 2023 and 2024 respectively. The five-point sampling method was used to collect soil from 0 to 30cm. After fully mixing, a 1.5kg soil sample was retained using the quartering method, and was naturally air-dried, impurities removed, ground and sifted for testing soil fertility indicators.

2.2 Soil Fertility Evaluation Methods

Evaluation Index. Seven indicators, pH, organic matter (OM), total nitrogen (TN), total phosphorus (TP), total potassium (TK), available phosphorus (AP) and available potassium (AK) were selected to evaluate soil fertility, and the measurement method was based on Soil Agrochemical Analysis (Third Edition) [14].

Evaluation method. Referring to the nutrient grading standards of the Second National Soil Census and previous research results [15, 16], the grading standards for soil fertility indicators for tobacco planting were determined (Table 1).

Table 1. Grading standards for soil fertility indicators of tobacco-growing soil

Level	pH	OM /(g/kg)	TN /(g/kg)	TP /(g/kg)	TK /(g/kg)	AP /(mg/kg)	AK /(mg/kg)
Extremely low	<4.5	<10	<0.75	<0.4	<10	<10	<100
Relatively low	4.5~5.5	10~20	0.75~1	0.4~0.6	10~15	10~20	100~150
Appropriate	5.5~6.5	20~30	1~1.5	0.6~0.8	15~20	20~30	150~200
Relatively high	6.5~7.0	30~40	1.5~2	0.8~1	20~25	30~40	200~300
Extremely high	>7.0	>40	>2	>1	>25	>40	>300

According to the different effects of soil pH, OM, TN, TP, TK, AP and AK on tobacco growth, and combined with the fertility evaluation standard, the corresponding membership function types and corresponding upper and lower limits were determined (Table 2). The parabolic and S-type membership functions are shown in Equations (1) and (2) respectively.

Table 2. Membership function types and parameter values of soil fertility evaluation indexes for tobacco field

Parameter	Parabolic type			S-type			
	pH	OM	TN	TP	TK	AP	AK
x_1	4.5	15	0.75	0.5	10	10	150
x_2	5.5	20	1				
x_3	6.5	30	1.5				
x_4	7.0	40	2	1	25	40	350

$$f(x) = \begin{cases} 0.1(x \le x1, x \ge x4) \\ \frac{0.9(x-x1)}{x2-x1} + 0.1(x1 < x < x2) \\ 1.0(x2 \le x \le x3) \\ 1.0 - \frac{0.9(x-x3)}{x4-x3}(x3 < x < x4) \end{cases} \quad (1)$$

$$f(x) = \begin{cases} 1.0(x \ge x4) \\ \frac{0.9(x-x1)}{x4-x1} + 0.1(x1 < x < x4) \\ 0.1(x \le x1) \end{cases} \quad (2)$$

The common factor variance is obtained through principal component analysis, and the weight of each indicator is calculated [17].

The integrated fertility index (IFI) is obtained by multiplying the membership degree and weight, as shown in Equation (3) [18]. The fertility suitability levels of tobacco planting soil are shown in Table 3 [19]. N_i and W_i are the membership value and corresponding weight value of the i-th evaluation indicator respectively.

$$f(x) = \sum_{i=1}^{n} N_i W_i \quad (3)$$

Table 3. Integrated fertility index of tobacco-growing soil

Grade	I	II	III	IV	V
Range	IFI≥0.8	0.6≤IFI<0.8	0.4≤IFI<0.6	0.2≤IFI<0.4	IFI<0.2
Fertility	High	Higher	Medium	Lower	Low

2.3 Data Analysis

Excel 2016 and SPSS 23.0 were used to analyze the distribution of each indicator and calculate the weights, and Origin2024 software was used to plot.

3 Results and Analysis

3.1 Nutrient Status of Tobacco-growing Soil

The soil fertility of tobacco planting is shown in Table 4 and 5. In 2023, the soil pH value ranged from 4.65 to 6.96, with an average of 5.25, and the coefficient of variation was small. The soil OM content ranged from 10.00 g/kg to 41.80 g/kg, with an average of 22.64 g/kg and a coefficient of variation of 34.26%. The variation range of soil AP was very large, which was 0.25 ~ 58.42 mg/kg, the mean value was 15.91 mg/kg, and the coefficient of variation was as high as 99.04%. The soil AK content ranged from 114.50 to 341.50 mg/kg, with an average of 220.91 mg/kg, and the coefficient of variation was less than 30%. The variation ranges of TN and TP in tobacco-planting soil were 0.66 ~ 1.88 g/kg and 0.45 ~ 1.27 g/kg, respectively, and the variation coefficients were all below 35%. The TK content ranged from 8.11 to 36.80 g/kg, and the coefficient

of variation was as high as 52.80%. In 2024, the variation ranges of pH, OM, AP and AK in tobacco-planting soil were 4.47 ~ 7.11, 9.99 ~ 42.61 g/kg, 0.74 ~ 62.45 mg/kg and 131.82~389.30 mg/kg, respectively. Except for the high variation coefficient of AP, the variation coefficients of other indexes were lower than 35%. The variation ranges of TN, TP and TK were 0.77 ~ 2.08 g/kg, 0.58 ~ 1.40 g/kg and 8.57 ~ 32.41 g/kg, respectively, and the coefficient of variation was less than 45%. The results showed that there were great differences in soil physical and chemical properties among different plots in the tobacco planting area, and the content of AP was very different. However, compared with 2023, the uneven content of soil phosphorus in 2024 was improved. The soil fertility in 2024 was improved compared with that in 2023, and the contents of AP, AK, TN and TP were improved to varying degrees.

Table 4. Nutrient content of tobacco-growing soil in Malong County in 2023

Indicators	pH	OM /(g/kg)	TN /(g/kg)	TP /(g/kg)	TK /(g/kg)	AP /(mg/kg)	AK /(mg/kg)
Amplitude of variation	4.65~6.96	10.00~41.80	0.66~1.88	0.45~1.27	8.11~36.80	0.25~58.42	114.50~341.50
Mean value	5.25	22.64	1.16	0.69	15.18	15.91	220.91
Standard deviation	0.50	7.76	0.33	0.21	8.02	15.76	58.71
Coefficient of variation /%	9.59	34.26	28.61	30.12	52.80	99.04	26.58

Table 5. Nutrient content of tobacco-growing soil in Malong County in 2024

Indicators	pH	OM /(g/kg)	TN /(g/kg)	TP /(g/kg)	TK /(g/kg)	AP /(mg/kg)	AK /(mg/kg)
Amplitude of variation	4.47~7.11	9.99~42.61	0.77~2.08	0.58~1.40	8.57~32.41	0.74~62.45	131.82~389.30
Mean value	5.39	23.25	1.24	0.78	15.05	19.14	256.39
Standard deviation	0.52	7.68	0.34	0.21	6.67	15.74	68.81
Coefficient of variation /%	9.74	33.01	27.34	26.71	44.32	82.22	26.84

3.2 Nutrient Distribution Frequency of Tobacco-planting Soil

The nutrient distribution frequency of tobacco-planting soil in Malong County from Fig.1 showed that the contents of OM and TP in tobacco-planting soil in Malong County were mostly in the range suitable for tobacco growth, while other nutrient contents were at a low or high level. The frequency of low soil pH value decreased from 83.87% in 2023 to 67.74% in 2024, and the frequency of suitable grade increased from 9.68% in 2023 to 22.58% in 2024. In 2023 and 2024, the proportion of the tobacco-growing soil with appropriate OM content in the tobacco planting area of Malong County was 41.94% and 51.61% respectively; the proportion of the soil with appropriate TN content was 41.94% and 54.84% respectively; and the proportion of the soil with appropriate TP content was 38.71% and 58.06% respectively. In 2023 and 2024, 54.84% of the TK content of tobacco-planting soil in Malong County was at a lower level; there were 51.61% and 38.71% of soil AP at very low levels, respectively. However, 54.84% and 41.93% of the soil AK content were at a high level. Compared with 2023, except for AK, all soil nutrients in 2024 will change in a direction suitable for tobacco growth. In general, the soil pH in Malong County is acidic; the contents of soil OM, TN and TP were suitable for tobacco growth. TK and AP content is low; the content of AK is high. In 2024, 70.98% of the soil pH was at extremely low and low levels; 67.74% of the soil TK content was at extremely low and low levels; 58.06% of the soil AP content was at extremely low and low levels; and 74.19% of the soil AK content was at extremely high and high levels.

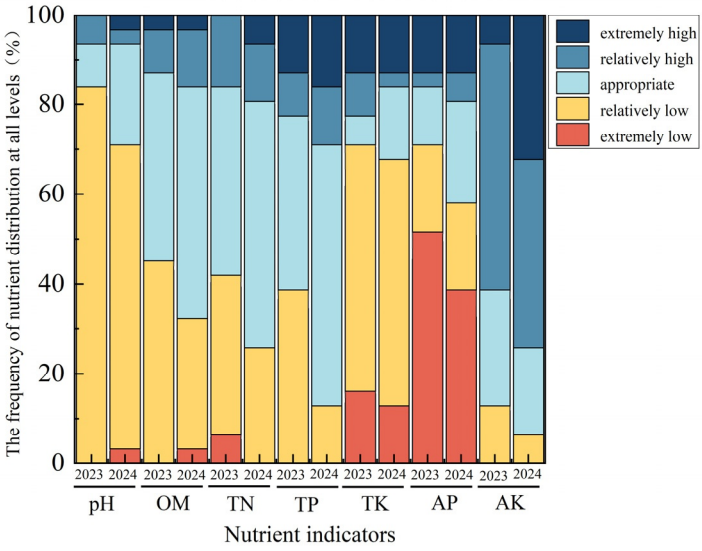

Fig. 1. Distribution frequency of pH value and nutrient content in tobacco planting soil in Malong County

3.3 Evaluation of Tobacco Soil Fertility

According to the common factor variance of principal component analysis (Table 6), the weight of each index is calculated, and the following results are obtained. In 2023 and 2024, the weights of soil OM, TN and TP contents were all greater than 0.15, while the soil pH, AP and AK contents were all greater than 0.1. Compared with 2023, the weights of soil OM, AK and TN in 2024 increased, while the weights of pH, AP, TP and TK decreased.

Table 6. Variances and weights of common factors in tobacco planting soil fertility indicators in Malong County

Indicators	2023		2024	
	Variance	Weight	Variance	Weight
pH	0.587	0.121	0.542	0.111
OM	0.802	0.165	0.915	0.187
AP	0.650	0.134	0.542	0.111
AK	0.564	0.116	0.728	0.149
TN	0.860	0.178	0.909	0.186
TP	0.844	0.174	0.772	0.158
TK	0.539	0.111	0.487	0.099

The results of soil fertility and fertility grade distribution frequency in Malong County are shown in the Fig. 2. In 2023 and 2024, the IFI values of tobacco-planting soil in Malong ranged from 0.23 to 0.86 and 0.31 to 0.89, respectively. According to the distribution of soil evaluation grade, the soil fertility of most points in the tobacco planting area of Malong County is at the level of grade II and grade III. Compared with 2023, the proportion of grade I and grade II soil increased, and the proportion of grade III and grade IV soil decreased in 2024. The proportion of grade I soil increased from 9.68% in 2023 to 12.90% in 2024, and the proportion of grade II soil increased from 32.26% in 2023 to 51.61% in 2024. Among them, the proportion of grade IV soil decreased from 22.58% in 2023 to 3.23% in 2024, and the soil fertility of tobacco planting in Malong County was higher than grade V, which was generally at a medium to high level and was more suitable for tobacco planting and growth.

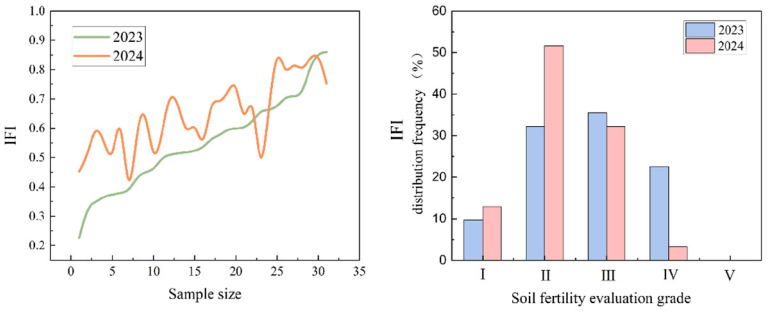

Fig. 2. Soil integrated fertility index and the distribution frequency of fertility grades of tobacco-growing soil in Malong County

4 Discussions

Compared with the traditional single soil nutrient index, the comprehensive evaluation system can quantitatively analyze the soil fertility in the study area more comprehensively and systematically. It uses principal component analysis, membership function model and fuzzy mathematics method to calculate a dimensionless value [20]. It has been reported that the research on tobacco planting soil in Qujing City and Malong County is mainly aimed at the influence of single index on tobacco growth and quality. There is no comprehensive and systematic evaluation method, which cannot fully reflect the soil fertility status in this area. In this study, the soil comprehensive fertility was evaluated by detecting 7 indexes of tobacco planting soil in Malong County. [21-24].

The results showed that the pH range of tobacco-planting soil in Malong County changed from 4.65 ~ 6.96 in 2023 to 4.47 ~ 7.11 in 2024. From the overall distribution frequency, the pH of most soil increased slightly, but the soil was still acidic, which was consistent with the research of Guo Huiting et al [6]. The optimum pH range for tobacco growth was 5.5 ~ 7.0 [25], and the optimum range was 5.5 ~ 6.5 [26]. Soil acidification can lead to soil compaction, poor aggregate structure, and inhibit the growth and development of tobacco roots [27]. It has been reported that low soil OM content can lead to short tobacco plants and low yield. If the content is too high, the tobacco leaf can be thickened, the content of protein and nicotine can increase, and the taste will be affected [28]. This study showed that the OM content of tobacco-growing soil in Malong County increased from 2023 to 2024, 45.16% of the samples were at a low level in 2023, and 51.61% of the samples were in the appropriate range in 2024, indicating that the OM content in the region has improved. It has been reported that high soil nitrogen content will delay the senescence of tobacco leaves and lead to late maturity of plants [29]. The results of this study showed that the contents of TN and TP in most sites of tobacco planting soil in Malong County were at the level suitable for tobacco growth, while the contents of TK and AP were at a low and extremely low level, respectively, but the AK was at a high level. Previous studies have shown that adequate supply of phosphate fertilizer can promote the development of tobacco roots and improve the nutrient absorption capacity of roots [30] ; it can also increase the content of sugar and volatile oil components in tobacco leaves, and improve the taste and aroma of flue-cured tobacco [31]. Tobacco is a potassium-loving crop. Potassium participates in the metabolism of tobacco plants and has an important impact on promoting nutrient absorption and transformation, increasing yield and quality [32]; potassium application can increase the potassium content in tobacco leaves and improve the processability of cigarettes [33].

5 Conclusion

The results of comprehensive evaluation of soil fertility showed that most of the soil fertility levels were grade II and grade III, indicating that the fertility status of tobacco planting soil in Malong County was at a medium to high level, and there was still some

room for improvement. To address a series of problems such as soil acidification, compaction, and uneven nutrient content (low TK and AP) caused by excessive fertilizer application during tobacco cultivation, some measures can be taken for soil improvement, such as reasonable crop rotation, green manuring, using slaked lime to adjust pH value, applying biological organic fertilizers and compost, and using bio-controlled bacteria for root irrigation, etc.

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