# Effects of Intercropping Sweet Potato on Economic Characteristics, Physical Properties and Chemical Composition of Flue-Cured Tobacco

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**Abstract:** This study used the tobacco variety Yunyan 87 as the material and conducted a field experiment with a three-factor three-level orthogonal design to investigate the effects of different sweet potato varieties, intercropping time, and intercropping density on the economic traits, physical properties, and chemical composition of tobacco plants under the intercropping of tobacco and sweet potatoes. The results showed that the economic traits, physical properties, and chemical composition of the intercropped tobacco plants were slightly better than those of the control (tobacco monoculture). Compared with the control, the yields, value, proportion of superior and medium tobacco leaves is 10.25%-20.42%, 0.58%- 1.31%, 2.48%-8.71%, and 2.91%-7.95% respectively; the leaf length, leaf width, leaf thickness, leaf weight, and leaf weight of quality is 1.21%-2.27%, 1.54%-2.66%, 9.61%-14.0%, 2.26%-3.29%, and 6.20%-7.35% respectively; total sugar, reducing sugar, total nitrogen, nicotine, and potassium ions is 1.07%-2.23%, 1.93%-2.34%, 0.69%-0.86%, 0.31%-0.60%, and 0.46%-0.64%, while chloride ions is 14.28% - 21.01% in the intercropped plants. Although there were differences in the physical properties and chemical composition of the tobacco leaves under the intercropping treatment, the tobacco leaves from different parts all met the standards of high-quality tobacco leaves. Among them, the T5 treatment had the largest increase in yield (20.42%) and the proportion of superior leaves (7.52%). Therefore, from an economic perspective, it is recommended to adopt the T5 treatment when intercropping tobacco and sweet potatoes in Fuquan City.

**Keywords:** Flue-Cured Tobacco; Intercropping; Sweet Potato; Economic Characteristics; Physical Properties; Chemical Composition

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# 1 Introduction

Fuquan City of Guizhou Province has a long history of tobacco cultivation, but the local area has been accustomed to a single-tobacco cultivation model for a long time, resulting in a low index of multiple planting in tobacco fields, land yield benefits and the comprehensive benefits; Moreover, most tobacco growing areas have experienced a decline in soil quality, aggravated tobacco pests and diseases, and reduced production and quality due to long-term single cropping of tobacco; Furthermore, under the policy of the central government emphasizing agriculture and grain production, the contradiction between tobacco and grain for land use has become more prominent. The rotation cropping of tobacco are very difficult, which severely restricts the development of the local tobacco industry and also affects the sustainable development of tobacco leaf production [5].

Relevant studies have shown that a reasonable intercropping pattern can not only effectively increase the multiple cropping index of tobacco fields and the utilization efficiency of light, temperature and heat, thereby increasing the yield per unit area of crops, effectively alleviating the land conflict between tobacco and grain, but also effectively reduce the occurrence of diseases and improve the coordination of chemical components of tobacco leaves [1, 3, 6]. Tobacco intercropping with other crops can achieve good results and significant increase benefits of the unit area with properly handled; If not handled properly, it not only affects the yield and quality of tobacco leaves, but also affects the yield and quality of intercropped crops [14]. The two modes of intercropping sweet potatoes between individual plant in single-row tobacco rack and on the tobacco ridge can increase the proportion of medium and high tobacco, the economic benefits per unit area, the multiple cropping index compared with the single cropping of tobacco [2]. Tobacco-sweet potato intercropping has little impact on tobacco quality, but it can increase the multiple planting index and achieve higher economic benefits in tobacco fields [11].

Therefore, in view of the actual situation of land competition between tobacco and food crops in the tobacco production of Fuquan City, the author investigated the effects of different planting periods, different varieties and different sowing densities of sweet potatoes on the economic characteristics, physical properties and chemical components of tobacco. The aim was to provide theoretical basis for effectively promoting the balanced development of tobacco and food crops as well as the sustainable and stable development of tobacco.

# 2 Materials and Methods

## 2.1 Experimental Location and Material

The experiment was conducted in Fuquan City, Guizhou Province (107°14'24" -107°45'35"E, 26°32'28" -27°02'23"N, altitude 1100 m) on April 2025. The field was yellow soil, and a 10-year single cropping was implemented for the plantation. The climate was subtropical humid monsoon with the average yearly temperature (16.1℃), precipitation (1431.1 mm) and sunshine (1253h), respectively. The physical and chemical properties of the test soil are as follows: pH value, organic matter, total nitrogen, total phosphorus, available nitrogen, available phosphorus and available potassium were respectively 6.79, 30.53g ⋅kg$^{-1}$, 1.76g ⋅kg$^{-1}$, 1.75 g ⋅kg$^{-1}$, 126.14 mg ⋅kg$^{-1}$, 23.63 mg ⋅kg$^{-1}$ and 306.15 mg ⋅kg$^{-1}$.

The tested variety Yunyan 87 of flue-cured tobacco is the main locally planted variety, with a planting density of 16500 plants/hm$^2$.

## 2.2 Experimental Design and Sampling

The tobacco plants were transplanted on April 25, 2005, and sweet potatoes were interplanted from June to July. The tobacco was grown in single-row ridge cropping (row spacing of 1.2 meters, plant spacing of 0.5 meters), while the sweet potatoes were double-row transplanted on both sides of the tobacco ridges (Figure 1A). The design was based on three factors and three levels according to the orthogonal design $L_3^3$ (Table 1), with factor A was the sweet potato variety (Shangshu 19, Shangshu 26, and Yanshu 25), factor B was the sweet potato sowing period (sowing on May 15, May 30, and June 15), and factor C was the sowing density (3300 plants/mu, 4400 plants/mu, 5500 plants/mu), and CK was the tobacco single cropping (Figure 1B), a total of 10 treatments, with each treatment repeated 3 times.

Table 1 Orthogonal design L33 for tobacco-sweet potatoes intercropping

| Treatments | A | B | C | Treatments | A | B | C |
|---|---|---|---|---|---|---|---|
| T1 | A1 | B1 | C1 | T6 | A2 | B3 | C1 |
| T2 | A1 | B2 | C2 | T7 | A3 | B1 | C3 |
| T3 | A1 | B3 | C3 | T8 | A3 | B2 | C1 |
| T4 | A2 | B1 | C2 | T9 | A3 | B3 | C2 |
| T5 | A2 | B2 | C3 | T10 | CK | | |


Figure 1 Schematic diagram of intercropping treatment and control field of tobacco

Fifteen representative plants with consistent growth conditions and no pests and diseases were selected from each planting area (after removing the top and base leaves), and 14 tobacco leaves from top to bottom were picked and baked respectively. After completion, the following measurements were taken:

(1) Economic characteristics: after the tobacco is ripe, the tobacco leaves in each processing area are harvested and woven separately, and the yield is calculated separately. After all tobacco leaves are harvested and baked, they are classified according to the *Tobacco' standard* (GB 2635-1992), and the production value is calculated based on the 2024 tobacco purchase price. The tobacco yield, proportion of medium tobacco, and proportion of high-grade tobacco are also counted [4].

(2) Physical characteristics, including length, width, thickness, single leaf weight and heavy leaf texture, according to*Survey and Measurement Methods for Tobacco Agronomic Characteristics* (YC/T 142-2010) [13].

(3) Chemical composition: After evaluating the physical properties, the tobacco sample is ground into fine powder for analysis of chemical composition, including total sugar, reducing sugar, total nitrogen, nicotine, potassium ion, and chloride ion content, according to the national standard for tobacco GB/T 2635-1992, YC/T 159-2002, YC/T 161-2002, YC/T 160-2002, YC/T 162-2002, YC/T 274-2008 [7].

## 2.3 Statistical Analyses

All data were organized using Microsoft Excel. The significance ($P<0.05$) of the differences between the mean values (3 replicates) of various indicators under different treatment methods was evaluated using one-way analysis of variance and least significant difference (LSD) test in SPSS 25.0 (IBM, USA).

# 3 Results

## 3.1 Effects of Intercropping on Economic Characteristics of Tobacco

Compared with CK, the yield per mu of T1-T9 treatment is increased 15.65%, 17.37%, 11.38%, 15.58%, 20.42%, 20.28%, 13.96%, 10.25%, and 11.13%, respectively. The value per mu is increased 0.67%, 0.91%, 0.58%, 0.68%, 1.05%, 1.30%, 0.53%, 1.31%, and 0.73%, respectively. The proportion of high-quality tobacco is increased 6.86%, 3.28%, 2.48%, 2.69%, 7.52%, 8.71%, 7.09%, 6.91%, and 3.14%, and the proportion of medium-quality tobacco is increased 4.26%, 2.91%, 6.32%, 6.91%, 6.18%, 3.31%, 7.27%, 7.95%, and 5.94%, respectively (Figure 2).

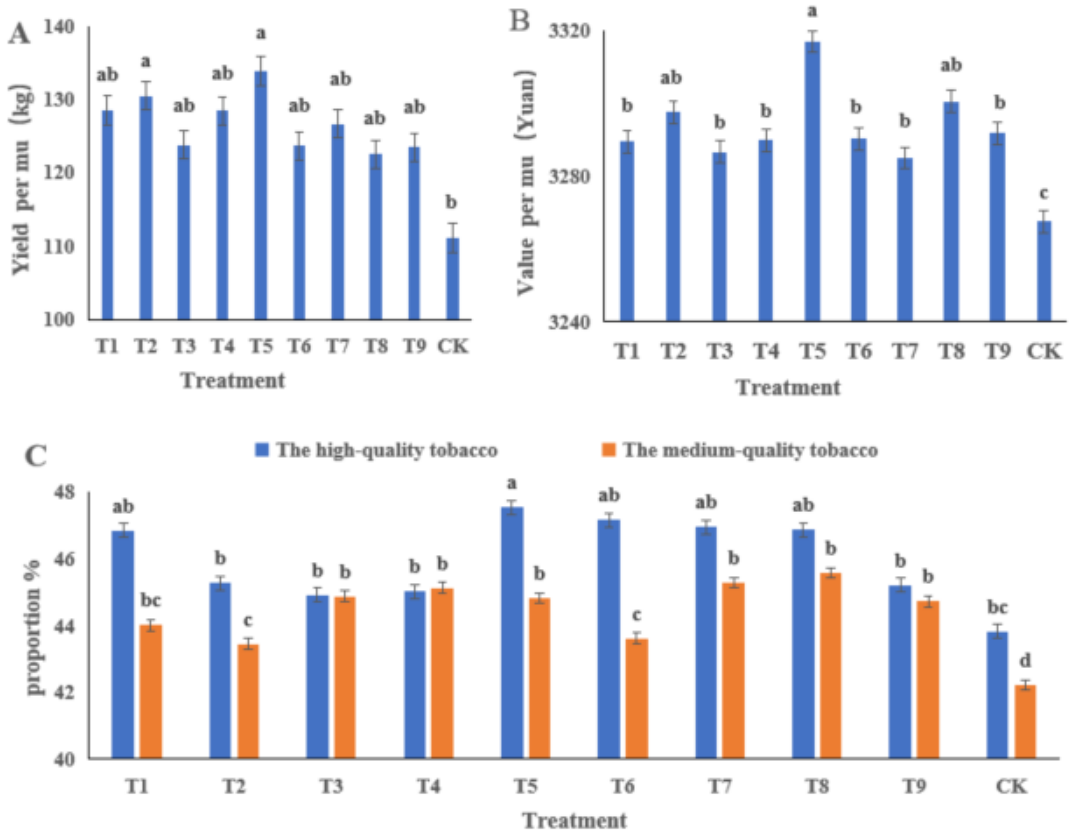


Figure 2 Effects of intercropping on economic characteristics of tobacco

## 3.2 Effects of Intercropping on Physical Characteristics of Tobacco

### 3.2.1 Effects of Intercropping on Length of Tobacco Leaves

The leaf length of tobacco plants treated with T1-T9 at different leaf positions was mostly longer than that of CK. Compared to CK in the T1-T9 treatments, the range increased of the 1st-14th leaf position is respectively 0.18% - 2.65%, 1.31% - 3.54%, 0.97% - 3.06%, 0.41% - 0.98%, 0.10% - 2.05%, 0.03% - 3.27%, 1.10% - 3.07%, 2.64% - 3.53%, 0.15% - 2.74%, 1.56% - 3.39%, 1.84% - 3.54%, 0.41% - 3.11%, 0.16% - 2.33%, 0.18% - 2.65% (Table 2).

Table 2 Effects of intercropping on length of tobacco leaves (Unit: cm)

| Treatments | The upper leaves | | | | The middle leaves | | |
|---|---|---|---|---|---|---|---|
| | The 1st leaf | The 2nd leaf | The 3rd leaf | The 4sh leaf | The 5sh leaf | The 6sh leaf | The 7sh leaf |
| T1 | 61.47±3.24ab | 63.53±1.32a | 65.62±3.94a | 65.34±3.84a | 66.29±2.84a | 67.62±3.74a | 67.96±4.73a |
| T2 | 61.22±2.25ab | 62.40±2.45ab | 64.84±3.72ab | 65.47±4.27a | 65.81±2.69b | 65.64±3.85b | 66.79±4.98ab |
| T3 | 62.73±3.28a | 63.16±2.64ab | 64.62±2.73ab | 65.22±5.63a | 65.77±3.04b | 66.39±3.27ab | 67.33±5.11a |
| T4 | 62.69±4.01a | 62.94±2.38ab | 64.79±1.85ab | 65.11±2.39a | 66.62±3.75a | 66.58±2.85ab | 66.96±3.85ab |
| T5 | 61.72±2.47ab | 63.74±3.02a | 65.81±2.49a | 65.43±3.74a | 66.92±4.27a | 67.78±3.94a | 67.99±4.14a |
| T6 | 61.47±2.53ab | 62.56±3.51ab | 64.76±1.83ab | 65.23±3.48a | 65.56±3.73b | 65.64±4.02b | 66.69±3.94ab |
| T7 | 62.48±2.32a | 63.43±2.84a | 64.67±3.05ab | 65.31±4.26a | 65.36±4.02b | 66.82±2.64a | 67.45±4.24a |
| T8 | 62.73±2.67a | 62.37±3.04ab | 64.85±2.64ab | 65.23±4.19a | 66.48±3.59a | 66.69±2.97ab | 66.83±2.94ab |
| T9 | 62.57±2.81a | 62.45±2.64ab | 64.29±2.49ab | 65.48±3.82a | 66.63±3.64a | 66.87±3.94ab | 67.11±3.25a |
| CK | 61.11±2.39ab | 61.56±2.73b | 63.67±2.71b | 64.84±4.27b | 65.29±4.11b | 65.62±3.75b | 65.96±3.54b |
| High quality leaf | 50-60 | | | | 65-75 | | |

| Treatments | The middle leaves | | | The lower leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 8sh leaf | The 9sh leaf | The 10sh leaf | The 11sh leaf | The 12sh leaf | The 13sh leaf | The 14sh leaf |
| T1 | 67.41±3.84a | 66.13±4.25ab | 65.26±3.74ab | 64.58±3.59ab | 63.63±4.28ab | 62.79±3.69ab | 61.47±3.46b |
| T2 | 67.43±3.21a | 67.18±3.67a | 66.23±3.89a | 64.36±4.35ab | 63.27±4.37ab | 62.18±5.03ab | 61.22±2.31b |
| T3 | 67.16±4.43a | 67.62±3.28a | 66.43±4.37a | 65.32±3.57a | 64.38±4.42a | 63.32±4.75a | 62.73±2.83a |
| T4 | 67.25±4.72a | 67.56±2.47a | 66.58±4.28a | 65.14±3.26a | 64.59±4.37a | 63.27±3.28a | 62.69±2.56a |
| T5 | 67.74±2.84a | 66.53±3.83ab | 65.26±3.28ab | 64.56±4.47ab | 62.85±3.83ab | 62.88±4.34ab | 61.72±3.19b |
| T6 | 67.56±2.96a | 67.28±3.59a | 66.37±2.57a | 64.94±4.32ab | 63.72±3.91ab | 62.81±3.75ab | 61.47±3.43b |
| T7 | 67.35±3.95a | 67.75±4.26a | 66.63±3.26a | 65.63±3.94a | 64.75±3.57a | 63.42±4.27a | 62.48±2.85a |
| T8 | 67.27±3.75a | 67.65±2.79a | 66.82±3.39a | 65.42±3.85a | 64.83±2.59a | 63.26±4.31a | 62.73±3.57a |
| T9 | 67.36±4.26a | 67.84±3.68a | 66.31±3.48a | 65.57±4.36a | 64.72±3.58a | 63.63±3.58a | 62.57±3.65a |
| CK | 65.43±4.84b | 66.03±4.37ab | 64.26±4.25a | 63.36±3.42b | 62.63±2.96b | 62.18±4.35ab | 61.11±2.49b |
| High quality leaf | 65-75 | | | 55-65 | | | |

From the average values of all leaf positions, the ranking of leaf length increase rate in T1-T9 treatment compared to CK is as follows: T7 (2.27%) > T9 (2.25%) > T8 (2.22%) > T4 (2.18%) > T3 (2.12%) > T5 (1.98%) > T1 (1.77%) > T6 (1.43%) > T2 (1.21%); In addition, the average upper leaf length (62.79-64.17cm), middle leaf length (65.43-67.03cm), and lower leaf length (62.32-64.12cm) of T1-T9 treatment all met the standards for high-quality tobacco leaves (upper leaf length 50-60cm, middle leaf length 65-75cm, lower leaf length 55-65cm).

### 3.2.2 Effects of Intercropping on Width of Tobacco Leaves

Compared to CK in the T1-T9 treatments, the range increased of the 1st-14th leaf position is respectively 0.66% - 3.05%, 0.44% - 2.88%, 1.05% - 3.33%, 0.77% - 2.83%, 1.03% - 2.12%, 0.57% - 3.63%, 1.11% - 4.78%, 0.81% - 3.35%, 3.81% - 5.96%, 0.42% - 2.76%, 2.53% - 4.56%, 0.46% - 1.58%, 1.53% - 3.43%, 0.83% - 3.88% (Table 3).

From the average values of all leaf positions, the ranking of leaf width increase rate in T1-T9 treatment compared to CK is as follows: T7 (2.66%) > T5 (2.52%) > T3 (2.49%) > T1 (2.39%) > T6 (2.31%) > T4 (1.99%) > T9 (1.98%) > T8 (1.93%) > T2 (1.54%). In addition, only the average upper leaf width (18.29-18.68cm) of T1-T9 treatment met the standard for high-quality tobacco leaves (upper leaf width 16-22cm), while the average middle leaf width (19.53-20.17cm) and lower leaf width (19.31-19.47cm) did not meet the standard for high-quality tobacco leaves (middle leaf width 23-30cm, lower leaf width 25-35cm).

Table 3 Effects of intercropping on width of tobacco leaves (Unit: cm)

| Treatments | The upper leaves | | | The middle leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 1st leaf | The 2nd leaf | The 3rd leaf | The 4sh leaf | The 5sh leaf | The 6sh leaf | The 7sh leaf |
| T1 | 18.23±1.45a | 18.29±2.47a | 18.64±3.12a | 18.83±2.34a | 19.04±3.48a | 19.33±3.58a | 19.95±3.58a |
| T2 | 18.34±1.62a | 18.46±2.39a | 18.52±3.27a | 18.66±2.48ab | 18.95±3.26a | 19.06±3.82ab | 19.44±3.53a |
| T3 | 18.45±1.23a | 18.47±2.24a | 18.68±2.38a | 18.85±1.74a | 19.11±3.59a | 19.36±3.27a | 19.92±3.28a |
| T4 | 18.48±2.32a | 18.55±2.68a | 18.79±2.46a | 18.96±2.63a | 19.05±3.75a | 19.38±2.83a | 19.47±3.93a |
| T5 | 18.66±1.84a | 18.36±1.37a | 18.89±1.93a | 18.99±1.96a | 19.14±3.54a | 19.45±1.46a | 19.88±2.83a |
| T6 | 18.52±1.63a | 18.56±1.38a | 18.82±2.46a | 18.96±2.49a | 19.15±3.94a | 19.52±1.66a | 19.82±2.94a |
| T7 | 18.28±2.26a | 18.73±1.56a | 18.93±2.13a | 19.03±3.16a | 19.12±2.75a | 19.64±2.48a | 20.12±1.74a |
| T8 | 18.37±2.73a | 18.62±2.17a | 18.57±1.84a | 18.76±3.26a | 18.97±3.18a | 19.21±3.25ab | 19.42±2.37a |
| T9 | 18.67±1.73a | 18.68±2.48a | 18.54±1.85a | 18.89±2.93a | 19.03±2.57a | 19.27±3.02ab | 19.56±3.15a |
| CK | 18.11±1.29a | 18.21±2.57a | 18.33±2.26a | 18.52±3.25ab | 18.76±2.84ab | 18.95±3.56b | 19.21±2.47a |
| High quality leaf | 16-22 | | | 23-30 | | | |

| Treatments | The middle leaves | | | The lower leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 8sh leaf | The 9sh leaf | The 10sh leaf | The 11sh leaf | The 12sh leaf | The 13sh leaf | The 14sh leaf |
| T1 | 20.33±3.85a | 21.05±4.73a | 21.33±4.38a | 20.42±4.38a | 19.83±2.57a | 19.21±4.38a | 18.3±2.37a |
| T2 | 19.83±3.56ab | 20.63±3.64ab | 21.14±5.03a | 20.26±4.92a | 19.65±3.92a | 19.35±4.26a | 18.24±2.48a |
| T3 | 20.03±2.78a | 21.05±3.58a | 21.56±5.27a | 20.37±4.45a | 19.78±3.54a | 19.24±3.62a | 18.19±3.27a |
| T4 | 19.85±2.47ab | 20.63±3.47ab | 20.84±4.83 | 20.22±4.47a | 19.69±3.84a | 19.57±3.33a | 18.22±3.31a |
| T5 | 20.17±3.69a | 21.05±4.02a | 21.32±3.95a | 20.35±3.97a | 19.38±2.75a | 19.29±3.49a | 18.19±2.57a |

| Treatments | The middle leaves | | | The lower leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 8$^{sh}$ leaf | The 9$^{sh}$ leaf | The 10$^{sh}$ leaf | The 11$^{sh}$ leaf | The 12$^{sh}$ leaf | The 13$^{sh}$ leaf | The 14$^{sh}$ leaf |
| T6 | 20.1±4.02a | 20.63±3.63b | 20.84±2.64ab | 20.26±3.75a | 19.72±4.27a | 19.44±4.21a | 18.23±2.83a |
| T7 | 20.23±3.79a | 21.05±3.49a | 21.16±4.96a | 20.53±5.16a | 19.45±3.84a | 19.21±2.57a | 18.04±3.48ab |
| T8 | 19.78±3.57ab | 20.63±4.24b | 20.92±4.63ab | 20.62±4.37a | 19.74±3.35a | 19.36±4.38a | 18.59±4.27a |
| T9 | 19.89±2.48ab | 20.63±3.27ab | 20.88±4.38ab | 20.39±5.55a | 19.82±2.25a | 19.35±3.65a | 18.11±2.54ab |
| CK | 19.67±3.75ab | 19.87±2.84b | 20.75±4.73ab | 19.72±3.67ab | 19.47±4.37a | 18.92±3.67ab | 17.89±2.85ab |
| High quality leaf | 23-30 | | | 25-35 | | | |

### 3.2.3 Effects of Intercropping on Thickness of Tobacco Leaves

Compared with CK in the T1-T9 treatments, the range increased of the 1$^{st}$-14$^{th}$ leaf position is respectively 9.52% - 23.8%, .26% - 15.78%, 5.55% - 16.6%, 5.26% - 10.5%, 0% - 11.7%, 5.88% - 11.76%, 0.6% - 13.12%, 6.87% - 23.52%, 0% - 12.5%, 0% - 20%, 7.14% - 28.57%, 13.37% - 22.35%, 8.33% - 33.33%, 11.11% - 33.33% (Table 4).

From the average values of all leaf positions, the ranking of leaf thickness reduction rate in T1-T9 treatment compared to CK is as follows: T4 = T5 = T6 (14.0%) > T2 (14.02%) > T9 = T3 (12.25%) > T1 = T8 (10.05%) > T7 (9.61%). In addition, the average values of upper leaf thickness (326-330μm), middle leaf thickness (284-292μm), and lower leaf thickness (241-267μm) treated with T1-T9 met the standards for high-quality tobacco leaves (upper leaf thickness of 300-350 μm, middle leaf thickness of 270-330μm, and lower leaf thickness of 220-280μm).

Table 4 Effects of intercropping on thickness of tobacco leaves (Unit: mm)

| Treaments | The upper leaves | | | The middle leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 1$^{st}$ leaf | The 2$^{nd}$ leaf | The 3$^{rd}$ leaf | The 4$^{sh}$ leaf | The 5$^{sh}$ leaf | The 6$^{sh}$ leaf | The 7$^{h}$ leaf |
| T1 | 0.33±0.13a | 0.33±0.16a | 0.32±0.15a | 0.32±0.21a | 0.30±0.23a | 0.30±0.19a | 0.29±0.17a |
| T2 | 0.32±0.11a | 0.33±0.16a | 0.32±0.21a | 0.31±0.18a | 0.30±0.25a | 0.29±0.17a | 0.29±0.33a |
| T3 | 0.31±0.09ab | 0.32±0.17a | 0.32±0.17a | 0.32±0.22a | 0.28±0.18a | 0.27±0.16ab | 0.28±0.28a |
| T4 | 0.32±0.13a | 0.32±0.16a | 0.33±0.16a | 0.33±0.18a | 0.29±0.19a | 0.29±0.14a | 0.28±0.19a |
| T5 | 0.33±0.14a | 0.32±0.09a | 0.33±0.14a | 0.33±0.11a | 0.27±0.24ab | 0.28±0.11ab | 0.28±0.21a |
| T6 | 0.33±0.08a | 0.32±0.15a | 0.33±0.22a | 0.33±0.08a | 0.28±0.17ab | 0.29±0.09a | 0.28±0.17a |
| T7 | 0.33±0.12a | 0.32±0.11a | 0.32±0.09a | 0.33±0.14a | 0.30±0.15a | 0.27±0.13ab | 0.29±0.11a |
| T8 | 0.32±0.07a | 0.33±0.09a | 0.32±0.18a | 0.33±0.18a | 0.29±0.16a | 0.28±0.15ab | 0.29±0.16a |
| T9 | 0.32±0.17a | 0.32±0.13a | 0.33±0.18a | 0.33±0.16a | 0.30±0.19a | 0.29±0.15a | 0.29±0.15a |
| CK | 0.34±0.15a | 0.33±0.15a | 0.34±0.15a | 0.33±0.15a | 0.32±0.15a | 0.32±0.16a | 0.31±0.09a |
| High quality leaf | 0.30-0.35 | | | 0.27-0.33 | | | |

| Treaments | The middle leaves | | | The lower leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 8$^{sh}$ leaf | The 9$^{sh}$ leaf | The 10$^{sh}$ leaf | The 11$^{sh}$ leaf | The 12$^{sh}$ leaf | The 13$^{sh}$ leaf | The 14$^{sh}$ leaf |
| T1 | 0.29±0.13a | 0.28±0.09a | 0.27±0.11a | 0.25±0.09a | 0.24±0.16a | 0.24±0.09a | 0.24±0.09a |
| T2 | 0.29±0.16a | 0.29±0.12a | 0.29±0.12a | 0.25±0.10a | 0.24±0.13a | 0.23±0.10ab | 0.25±0.11a |
| T3 | 0.29±0.18a | 0.28±0.13a | 0.27±0.13a | 0.25±0.11a | 0.24±0.15a | 0.24±0.09a | 0.24±0.09a |
| T4 | 0.29±0.11a | 0.29±0.08a | 0.28±0.14a | 0.25±0.19a | 0.24±0.13a | 0.25±0.08a | 0.23±0.12a |
| T5 | 0.29±0.12a | 0.29±0.09a | 0.28±0.13a | 0.25±0.16a | 0.25±0.14a | 0.24±0.11a | 0.25±0.07a |
| T6 | 0.29±0.13a | 0.29±0.11a | 0.27±0.21a | 0.25±0.21a | 0.24±0.11a | 0.24±0.12a | 0.24±0.12a |
| T7 | 0.28±0.14a | 0.29±0.12a | 0.28±0.18a | 0.26±0.22a | 0.25±0.10a | 0.23±0.10a | 0.23±0.11a |
| T8 | 0.28±0.13a | 0.29±0.14a | 0.28±0.19a | 0.26±0.17a | 0.24±0.14a | 0.24±0.12a | 0.24±0.10a |
| T9 | 0.28±0.12a | 0.28±0.15a | 0.29±0.1a | 0.26±0.14a | 0.25±0.16a | 0.23±0.16ab | 0.24±0.09a |
| CK | 0.31±0.15a | 0.31±0.12a | 0.30±0.12a | 0.27±0.13a | 0.27±0.18a | 0.26±0.09a | 0.26±0.09a |
| High quality leaf | 0.27-0.33 | | | 0.22-0.28 | | | |

### 3.2.4 Effects of Intercropping on Weigth of Tobacco Leaves

Compared to CK in the T1-T9 treatments, the range increased of the 1st-14th leaf position is respectively 1.21% - 3.57%, 1.71% - 3.57%, 1.15% - 4.38%, 0.40% - 1.29%, 0.92% - 3.53%, 1.97% - 3.20%, 1.54% - 4.29%, 1.06% - 4.09%, 1.63% - 3.54%, 2.13% - 5.39%, .10% - 7.63%, 2.43% - 4.52%, 1.90% -4.69%, 1.93% - 7.17% (Table 5).

Table 5 Effects of intercropping on weigth of tobacco leaves (Unit: g)

| Treaments | The upper leaves | | | The middle leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 1st leaf | The 2nd leaf | The 3rd leaf | The 4sh leaf | The 5sh leaf | The 6sh leaf | The 7h leaf |
| T1 | 13.36±4.56a | 13.47±3.54a | 12.53±4.27a | 12.23±2.57a | 12.18±3.33ab | 11.84±3.59a | 11.24±3.34ab |
| T2 | 13.64±.3.92a | 13.21±3.98a | 12.59±4.38a | 12.15±2.48a | 12.04±3.47ab | 11.77±3.47a | 11.14±3.54b |
| T3 | 13.53±2.78a | 13.38±2.87a | 12.47±4.92a | 12.23±2.53a | 12.33±3.58a | 11.81±3.48a | 11.28±3.37ab |
| T4 | 13.54±4.56a | 13.27±2.55a | 12.68±2.84a | 12.29±3.58a | 11.99±4.26b | 11.79±4.32a | 11.25±3.96ab |
| T5 | 13.64±3.26a | 13.36±3.42a | 12.52±3.28a | 12.29±3.46a | 12.15±3.91ab | 11.92±5.18a | 11.46±3.17ab |
| T6 | 13.48±4.32a | 13.25±5.32a | 12.25±3.58a | 12.18±4.25a | 12.28±2.73a | 11.86±4.38a | 11.34±2.38ab |
| T7 | 13.39±3.94a | 13.44±4.38a | 12.42±4.21a | 12.26±4.34a | 12.09±2.35ab | 11.76±3.26a | 11.33±2.57ab |
| T8 | 13.65±2.65a | 13.48±3.92a | 12.26±3.75a | 12.24±3.98a | 11.88±4.15b | 11.92±2.75a | 11.27±3.25ab |
| T9 | 13.33±3.59a | 13.46±4.29a | 12.44±3.28a | 12.21±3.67a | 12.27±3.37a | 11.89±3.28a | 11.36±4.45ab |
| CK | 13.83±4.27a | 13.71±3.73a | 12.83±3.64a | 12.34±3.47a | 12.45±2.84a | 12.16±3.16a | 11.64±2.97a |
| High quality leaf | 9-12 | | | 7-11 | | | |

| Treaments | The middle leaves | | | The lower leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 8sh leaf | The 9sh leaf | The 10sh leaf | The 11sh leaf | The 12sh leaf | The 13sh leaf | The 14sh leaf |
| T1 | 10.83±3.19a | 10.23±3.27a | 9.38±3.28a | 8.40±2.47ab | 8.23±2.38a | 7.60±2.58a | 6.85±1.89ab |
| T2 | 10.93±3.26a | 10.37±3.34a | 9.37±3.16a | 8.66±3.28ab | 8.24±2.47a | 7.58±2.48a | 6.88±2.26ab |
| T3 | 10.79±3.33a | 10.23±2.78a | 9.34±2.64a | 8.35±2.65ab | 8.33±3.28a | 7.63±3.26a | 6.91±2.25a |
| T4 | 10.82±3.13a | 10.44±2.49a | 9.42±2.81a | 8.64±3.25ab | 8.27±3.47a | 7.53±1.48a | 6.76±2.85ab |
| T5 | 10.77±2.98a | 10.22±3.15a | 9.43±1.73a | 8.55±3.47ab | 8.41±1.79a | 7.65±2.36a | 6.73±2.01ab |
| T6 | 10.84±2.68a | 10.29±3.34a | 9.44±2.36a | 8.72±1.94ab | 8.37±3.02a | 7.51±1.94a | 6.91±2.37a |
| T7 | 11.11±1.90a | 10.32±2.94a | 9.63±3.46a | 8.44±2.75ab | 8.28±2.58a | 7.67±2.46a | 6.84±1.74ab |
| T8 | 10.93±3.45a | 10.41±2.48a | 9.45±3.81a | 8.76±2.49ab | 8.42±2.46a | 7.55±3.42a | 6.96±2.25a |
| T9 | 11.03±2.94a | 10.27±2.67a | 9.56±2.95a | 8.94±3.15a | 8.35±3.13a | 7.73±3.22a | 7.11±1.64a |
| CK | 11.23±2.58a | 10.62±2.35a | 9.82±3.13a | 9.04±2.84a | 8.62±2.86a | 7.88±1.67a | 7.25±2.21a |
| High quality leaf | 7-11 | | | 6-8 | | | |

From the average values of all leaf positions, the ranking of single leaf weight reduction rate in T1-T9 treatment compared to CK is as follows: T1 (3.29%) > T2 (3.14%) > T3 (3.13%) > T4 (3.08%) > T6 (3.06%) > T7 (2.89%) > T5 (2.81%) > T8 (2.76%) > T9 (2.26%). In addition, the average single leaf weight of the middle leaves (9.37-11.32g) and lower leaves (6.85-7.92g) treated with T1-T9 met the standards for high-quality tobacco leaves (single leaf weight of the upper leaves 9-12g, single leaf weight of the middle leaves 7-11g, and single leaf weight of the lower leaves 6-8 g); However, the average weight per leaf of the upper leaves (12.15-12.90g) exceeded the standard for high-quality tobacco leaves (9-12g).

### 3.2.5 Effects of Intercropping on Heavy Leaf Texture of Tobacco Leaves

Compared to CK in the T1-T9 treatments, the range reduced of the 1st-14th leaf position is respectively 2.92% - 4.59%, 3.85% - 5.34%, 4.21% - 5.57%, 4.78% - 10.52%, 2.42% - 3.77%, 3.65% - 7.81%, 8.50% - 14.7%, .43% - 11.9%, 6.94% - 10.29%, 7.5% - 9.09%, 3.39% - 6.67%, 2.92% - 8.28%, 5.28% - 15.22%, 5.62% - 9.33% (Table 6).

Table 6 Effects of intercropping on heavy leaf texture of tobacco leaves (Unit: g/m$^2$)

| Treaments | The upper leaves | | | The middle leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 1st leaf | The 2nd leaf | The 3rd leaf | The 4sh leaf | The 5sh leaf | The 6sh leaf | The 7h leaf |
| T1 | 87.18±16.37 | 85.37±22.24 | 82.34±22.15 | 78.16±21.46 | 73.47±19.43 | 66.55±21.34 | 61.73±18.32 |
| T2 | 87.92±13.42 | 86.52±18.37 | 83.27±21.32 | 80.38±26.82 | 73.35±10.36 | 67.64±22.32 | 60.33±19.46 |
| T3 | 87.34±15.46 | 86.64±17.45 | 82.91±19.18 | 78.16±22.32 | 74.47±14.32 | 69.55±19.27 | 64.73±22.26 |
| T4 | 87.48±16.35 | 86.55±11.83 | 83.16±20.22 | 77.38±25.45 | 74.35±16.53 | 68.64±18.54 | 63.33±23.32 |
| T5 | 86.92±12.26 | 86.72±16.27 | 82.88±26.47 | 79.16±22.27 | 73.47±14.47 | 67.55±19.38 | 64.73±24.37 |
| T6 | 87.92±13.89 | 86.68±18.46 | 83.42±22.64 | 82.38±21.34 | 72.35±16.34 | 67.64±14.43 | 60.33±21.34 |
| T7 | 88.46±14.63 | 86.54±22.24 | 83.52±20.73 | 78.16±25.42 | 72.47±23.27 | 67.55±13.28 | 61.73±20.56 |
| T8 | 87.84±10.21 | 86.62±20.21 | 83.34±18.94 | 78.38±28.36 | 71.35±22.54 | 68.64±17.46 | 62.33±19.42 |
| T9 | 88.03±11.52 | 86.59±17.37 | 83.22±21.06 | 79.54±22.33 | 71.33±12.23 | 69.45±15.54 | 63.77±18.36 |
| CK | 91.15±12.74 | 90.23±15.55 | 87.19±18.45 | 86.54±28.42 | 76.33±16.64 | 72.18±20.87 | 70.77±20.43 |
| High quality leaf | 80-100 | | | 70-90 | | | |

| Treaments | The middle leaves | | | The lower leaves | | | |
|---|---|---|---|---|---|---|---|
| | The 8sh leaf | The 9sh leaf | The 10sh leaf | The 11sh leaf | The 12sh leaf | The 13sh leaf | The 14sh leaf |
| T1 | 65.39±15.43 | 62.53±16.45 | 61.28±20.32 | 58.16±10.43 | 52.28±23.26 | 44.34±15.45 | 41.92±8.57 |
| T2 | 66.44±16.52 | 63.58±14.32 | 61.61±15.24 | 57.67±11.36 | 54.18±22.33 | 43.24±13.32 | 41.39±9.58 |
| T3 | 67.39±14.67 | 62.67±16.36 | 60.36±16.25 | 56.78±12.13 | 52.47±23.34 | 45.26±16.26 | 40.96±11.46 |
| T4 | 66.44±15.46 | 63.54±18.26 | 61.42±17.43 | 58.35±11.32 | 51.18±18.65 | 46.24±15.43 | 40.25±12.37 |
| T5 | 68.39±13.38 | 62.47±16.37 | 61.28±15.36 | 56.33±10.36 | 52.28±16.47 | 41.37±10.28 | 41.22±11.64 |
| T6 | 66.44±15.29 | 63.43±16.43 | 60.57±16.47 | 57.28±9.57 | 54.25±18.56 | 42.24±9.78 | 42.39±10.38 |
| T7 | 64.39±17.34 | 62.53±17.45 | 60.45±14.36 | 56.16±10.43 | 52.28±16.75 | 42.11±12.34 | 41.92±9.43 |
| T8 | 66.44±13.54 | 62.44±18.27 | 60.61±15.54 | 57.39±14.64 | 53.18±15.54 | 44.24±8.28 | 41.39±8.39 |
| T9 | 65.09±14.33 | 61.26±19.26 | 60.23±13.32 | 56.23±12.27 | 51.82±14.55 | 45.83±10.36 | 40.45±10.65 |
| CK | 73.11±12.23 | 68.43±15.33 | 66.23±11.23 | 60.23±15.36 | 55.82±16.38 | 48.83±11.54 | 44.45±11.23 |
| High quality leaf | 70-90 | | | 60-70 | | | |

From the average values of all leaf positions, the ranking of leaf mass reduction rate in T1-T9 treatment compared to CK is as follows: T7 (7.35%) > T1 (7.10%) > T9 (6.89%) > T8 (6.75%) > T5 (6.69%) > T6 (6.43%) > T2 (6.41%) > T4 (6.34%) > T3 (6.20%). In addition, only the average weight of upper leaves (83.76-85.1g/m$^2$) treated with T1-T9 met the standard for high-quality tobacco leaves (upper leaf weight 80-100g/m$^2$); However, the average values of leaf mass in the middle (65.15-66.52g/m$^2$) and lower (47.81-49.17g/m$^2$) did not meet the standards for high-quality tobacco leaves (middle leaf mass 70-90g/m$^2$, lower leaf mass 60-70g/m$^2$).

## 3.3 Effects of Intercropping on Chemical Composition of Tobacco

### 3.3.1 Effects of Intercropping on Total Sugar Content of Tobacco

Compared to CK in the T1-T9 treatments, the range increased of the 1st-14th leaf position is 0.76% - 4.33%, 2.42% - 4.66%, 1.5% - 3.95%, 2.60% - 5.47%, 2.25% - 5.34%, 1.16% - 4.58%, 1.68% - 3.72, 0.46% - 1.65%, 2.07% - -0.53%, 0.84% - 0.26%, 0.20% - 2.37%, 1.16% - 4.58%, 0.66% - 1.29%, 0.08% - 0.43%, respectively (Figure 3).

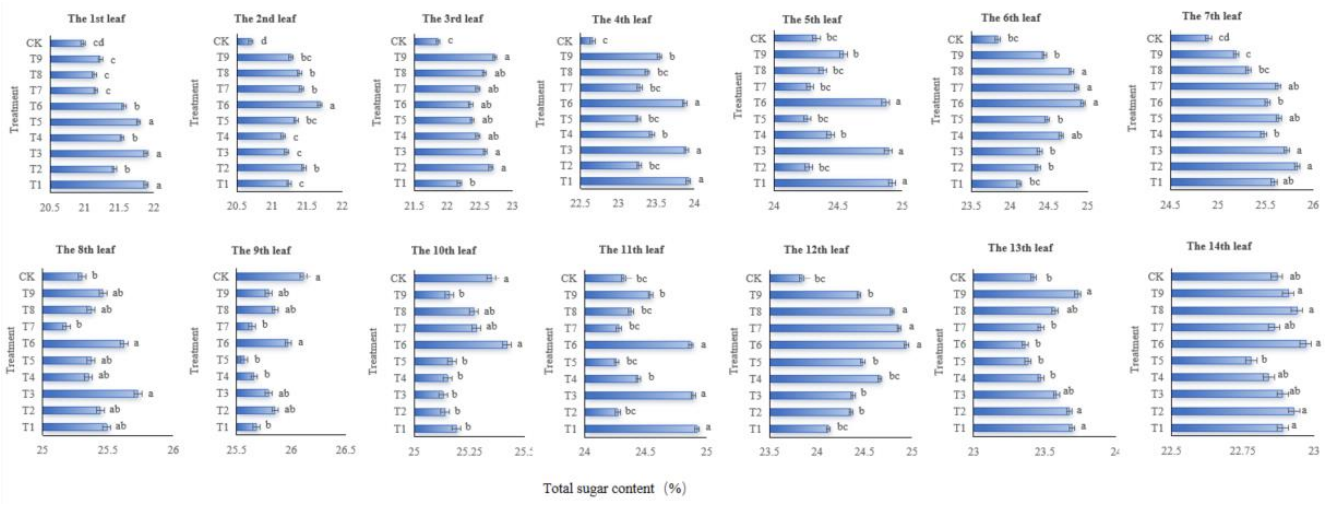


Figure 3 Effects of intercropping on total sugar content of tobacco

From the average values of all leaf positions, the ranking of the total sugar content increase rate in T1-T9 treatment compared to CK is as follows: T6 (2.23%) > T3 (1.91%) > T1 (1.58%) > T8 (1.36%) > T9 (1.31%) > T2 (1.30%) > T4 (1.25%) > T7 (1.22%) > T5 (1.07%).

### 3.3.2 Effects of Intercropping on Reducing Sugar Content of Tobacco

Compared to CK in the T1-T9 treatments, the range decreased of the 1st-14th leaf position is respectively 2.13% - 3.17%, 2.83% - 3.85%, 1.63% - 2.63%, 1.60% - 2.35%, 2.73% - 3.27%, 1.59% - 2.28%, 1.31% - 2.21%, 6.07% - 7.49%, 6.7% - 7.48%, 4.35% - 5.28%, 3.32% - 5.04%, 3.03% - 3.99%, 2.75% - 3.62%, 1.42% - 2.37% (Figure 4).

From the average values of all leaf positions, the ranking of the reduction rate of reducing sugar content in T1-T9 treatment compared to CK is as follows: T2 (2.34%) > T7 (2.31%) > T4 (2.30%) > T1 (2.09%) > T5 (2.07%) > T8 (2.06%) > T3 (2.05%) > T9 (1.96%) > T6 (1.93%).

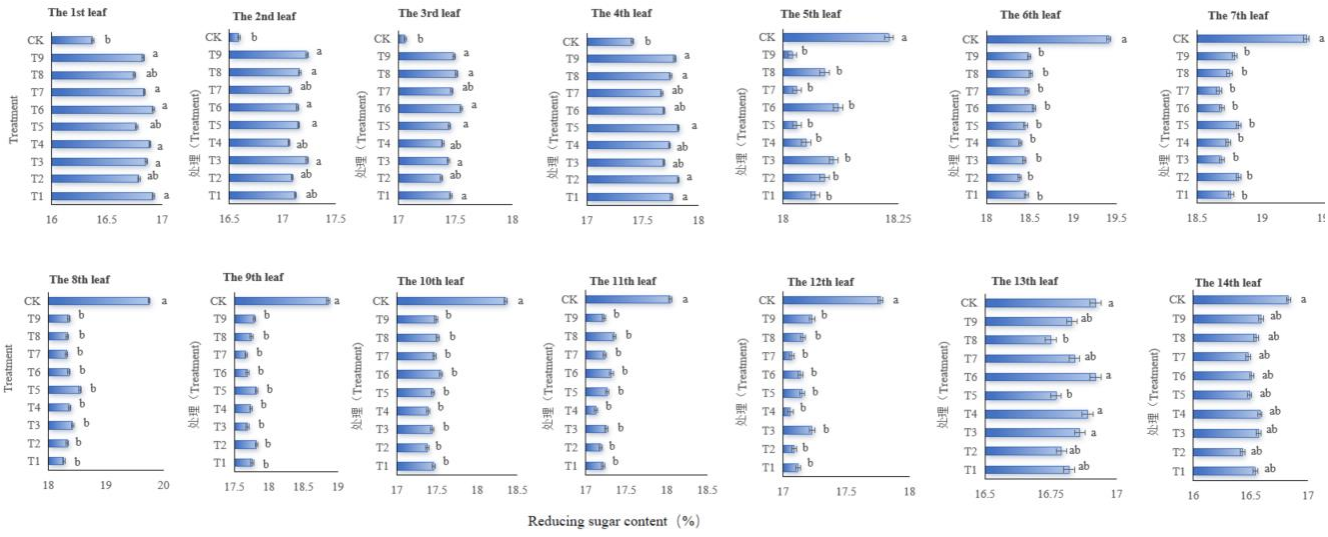


Figure 4 Effects of intercropping on reducing sugar content of tobacco

### 3.3.3 Effects of Intercropping on Total Nitrogen Content of Tobacco

Compared with CK in the T1-T9 treatment, the range increased of the 1st-14th leaf position is respectively 3.13% - 9.0%, 4.59% - 6.5%, 8.36% - 10.26%, 9.52% - 11.9%, 10.37% - 14.52%, 8.08% - 11.06%, 7.48% - 14.09%, 8.18% - 13.63%, 7.14% - 12.38%, 5.79% - 11.11%, 2.43% - 6.34%, 2.85% - 5.71%, 2.05% - 12.82%, 2.63% - 6.84% (Figure 5).

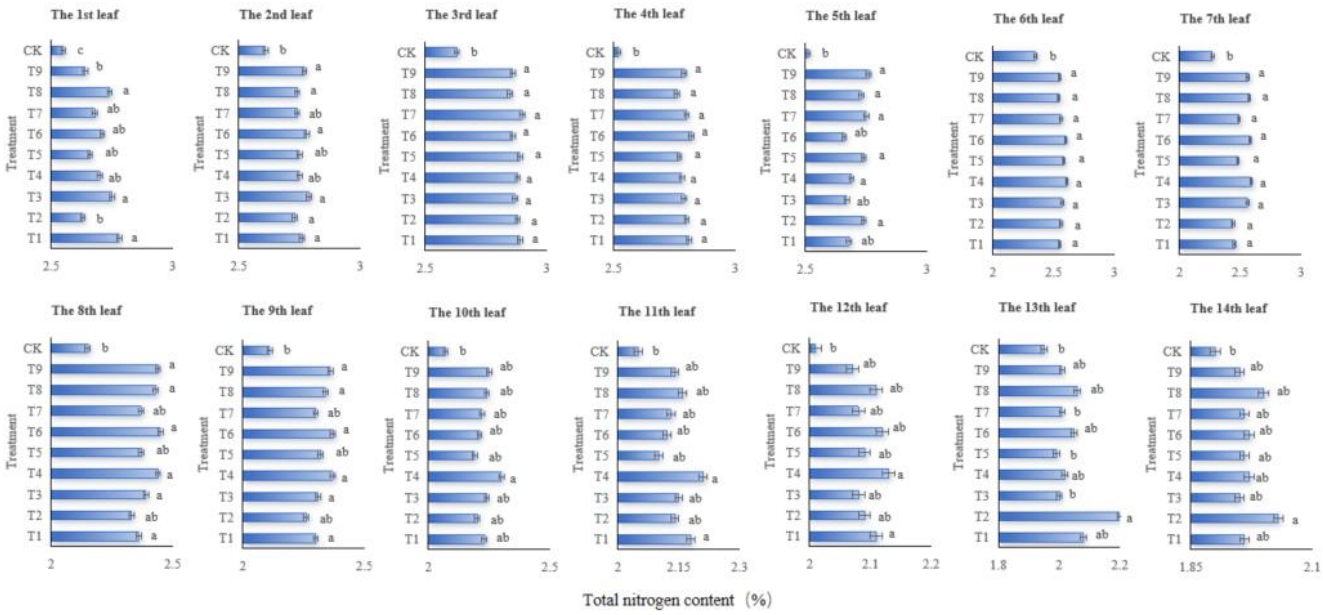


Figure 5 Effects of intercropping on total nitrogen content of tobacco

From the average values of all leaf positions, the ranking of the increase rate of total nitrogen content in T1-T9 treatment compared to CK is as follows: T4 (0.86%) > T6 (0.82%) > T8 (0.81%) > T9 (0.78%) > T1 (0.77%) > T3 (0.76%) > T2 (0.74%) > T7 (0.72%) > T5 (0.69%).

### 3.3.4 Effects of Intercropping on Nicotine Content of Tobacco

Compared to CK in the T1-T9 treatment, the range increased of the 1st-14th leaf position is respectively 2.60% - 5.65%, 0-4.34%, 1.3% - 6.0%, 1.36% - 6.36%, 2.38% - 5.91%, 1.42% - 3.8%, 4.27% - 10.69%, 6.11% - 11.11%, 4.70% - 13.52%, 3.02% - 8.45%, 3.04% - 6.70%, .36% - 5.62%, 1.91% - 3.18%, 1.31% - 5.27% (Figure 6).

From the average values of all leaf positions, the ranking of nicotine content increase rate in T1-T9 treatment compared to CK is as follows: T3 (0.60%) > T2 (0.54%) > T1 (0.52%) > T4 (0.47%) > T5 (0.46%) > T6 (0.44%) > T8 (0.42%) > T7 (0.41%) > T9 (0.31%).

### 3.3.5 Effects of Intercropping on $K^+$ Content of Tobacco

Compared with CK in the T1-T9 treatment, the range increased of the 1st-14th leaf position is respectively 3.33% - 7.61%, 5.23% - 6.66%, 1.73% - 6.19%, 4.76% - 7.61%, 5.71% - 8.57%, 7.89% - 13.15%, 2.03% - 6.59%, 4.21% - 7.36%, 3.82% - 6.01%, 6.34% - 11.11%, 4.14% - 8.29%, 2.71% - 7.1%, 3.95% - 7.90%, 1.70% - 7.38% (Figure 7).

From the average values of all leaf positions, the ranking of potassium content increase rate in T1-T9 treatment compared to CK is as follows: T4 (0.64%) > T1 (0.61%) > T3 (0.60%) > T2 (0.59%) > T6 (0.57%) > T5 (0.56%) > T7 (0.53%) > T8 (0.52%) > T9 (0.46%).

### 3.3.6 Effects of Intercropping on $Cl^-$ Content of Tobacco

Compared to CK in the T1-T9 treatment, the range increased of the 1st-14th leaf position is respectively 12.16% - 35.13%, 3.18% - 30.43%, 9.45% - 17.56%, 8.86% -13.92%, 9.41% - 16.47%, 8.39% - 24.13%, 11.23% - 19.10%, 10.86% - 19.56%, 5.95% - 19.04%, 7.22% - 27.71%, 9.75% - 34.14%, 7.14% - 25.01%, 11.11% - 22.22%, 16.32% -23.46% (Figure 8).

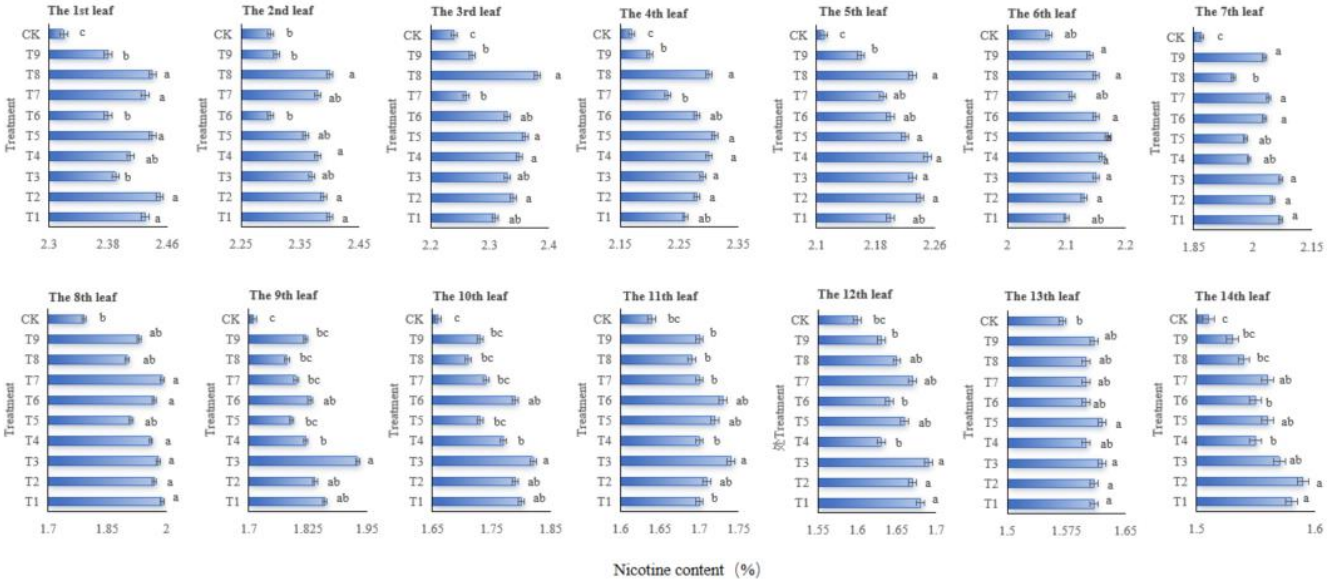


Figure 6 Effects of intercropping on nicotine content of tobacco

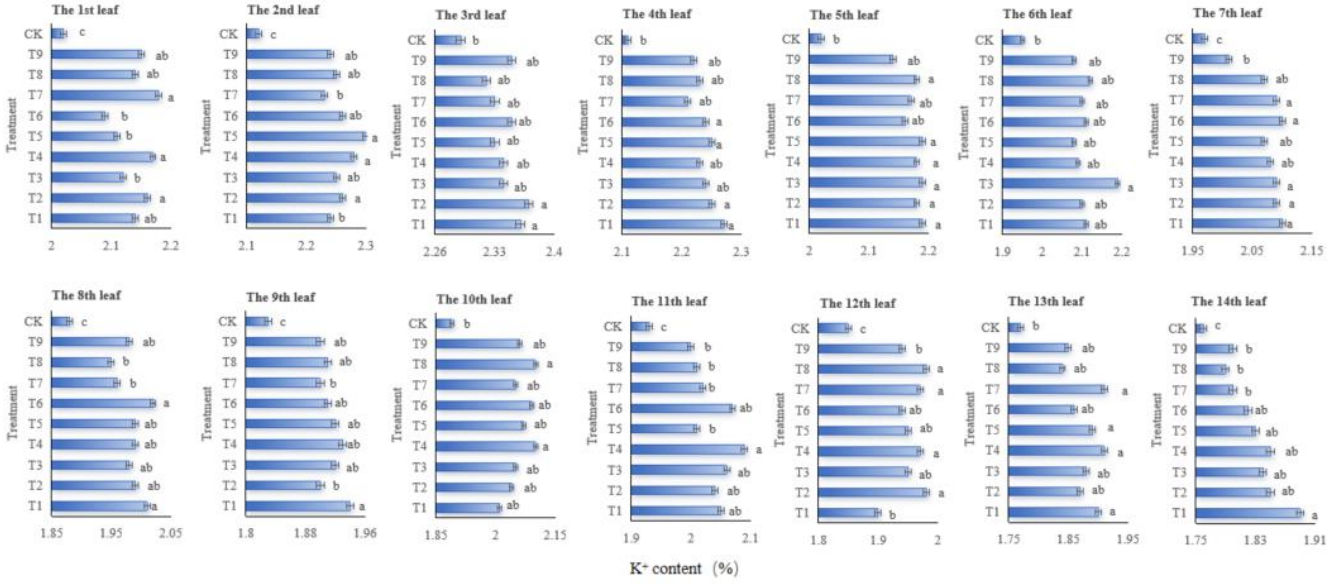


Figure 7 Effects of intercropping on $K^+$ content of tobacco

From the average values of all leaf positions, the ranking of chlorine content reduction rate in T1-T9 treatment compared to CK is as follows: T9 (21.01%) > T6 (19.04%) > T8 (18.87%) > T5 (17.51%) > T7 (17.43%) > T4 (15.81%) > T1 (15.56%) > T2 (15.47%) > T3 (14.28%).

# 4 Discussion

In terms of cultivation theory, tobacco and sweet potato are both potassium-loving crops, which are not suitable for intercropping and avoid to affecting the quality of tobacco. But this study results show that the tobacco-sweet potato intercropping can improve the economic characteristics of tobacco plants. Among them, compared to CK, the increase in mu output is 10.25-17.37%, the output value per mu is 0.58-1.31%, the proportion of high and medium quality is 2.48-8.71% and 2.91-7.95%, which is consistent with the conclusion that "the tobacco-sweet potatoes intercropping can increase the proportion of high and medium quality of tobacco as compared with the single cropping tobacco" [10].

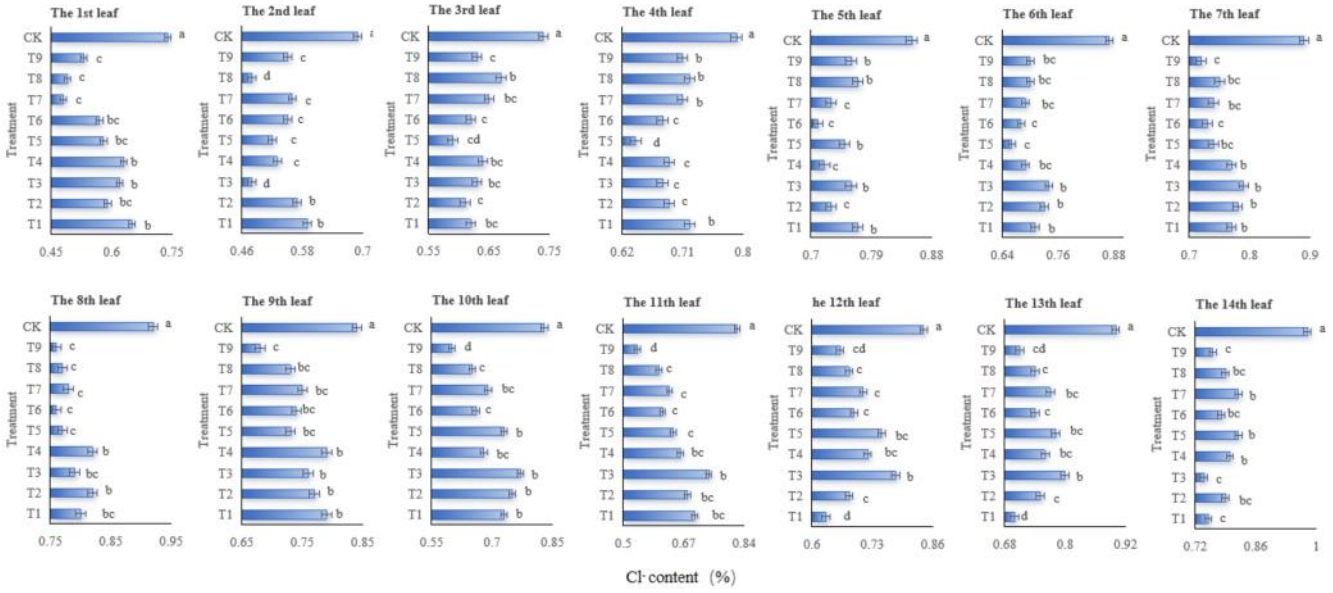


Figure 8 Effects of intercropping on $Cl^-$ content of tobacco

Tobacco-sweet potato intercropping promotes the yellowing maturity and improves the maturity of tobacco leaves. Judging from the physical characteristics of tobacco leaves after baking, the leaf length and thickness of different leaf positions, the width of the upper leaf and the leaf weight of the upper leaf, the weight of the single leaf in the middle leaf and the single leaf weight of the lower leaf meet the standard of high-quality tobacco leaves, indicating that the sweet potato set of tobacco plants has a certain impact on the single-leaf weight of the upper tobacco leaves, which is consistent with the conclusion that "the yield of upper tobacco leaves will decrease slightly" [12, 13].

Under different treatments, there are certain differences in the chemical composition of tobacco after baking. Among them, the reducing sugar of the middle and lower tobacco leaves is lower than that of CK. However, on the whole, the quality of tobacco-sweet potato intercropping is improved compared with the single cropping of tobacco (CK), which is consistent with the conclusion that "the yield of upper tobacco leaves will decrease slightly" [2].

The results of the study showed that the T5 treatment was the best on promoting the yellowing maturity, improving the physical characteristics and coordinating the content of chemical components in tobacco leaves, which was consistent with the conclusion that "the effect of intercropping sweet potatoes after 25-40 days of transplant tobacco was better" [8], but the results of the study showed that it was appropriate to intercropping sweet potatoes with tobacco in early July [9].

## 5 Conclusion

Compared with the CK, the economic characteristics, physical characteristics and chemical composition of tobacco-sweet potato intercropping are slightly better than CK; among them, the yield per mu, output value of each mu and the proportion of high-quality tobacco of T5 treatment is the highest. Therefore, from the perspective of economic characteristics, it is recommended to carry out T5 treatment of tobacco-sweet potato intercropping in Fuquan City.

## Author Contributions

ZHONG Jun wrote the first draft of the manuscript, Qiang Li performed the statistical analysis, Xizhong Zhang contributed to design of the study; Jiayi Li, Ting Lei, Yuming Wu, Xingqi Wei, Xiaoang Liu contributed to conception of the study. Qiang Li are the corresponding author. All authors contributed to manuscript revision, read, and approved the submitted version.

## Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships.

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