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Effects of Different Potash Regimes on the Leaf Structure and Some Physiological and Biochemical and Agronomic Traits of Flue-cured Tobacco

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Abstract [**Objectives**] This study was conducted to investigate the effects of different potash regimes on the leaf structure and some physiological and biochemical and agronomic traits of flue-cured tobacco. [**Methods**] JSZX-09-011F1, a new strain of flue-cured tobacco, was selected as the experimental material, and the effects of different quantities and modes of application on the leaf structure and certain physiological and agronomic traits of flue-cured tobacco were investigated. [**Results**] The K treatment was superior to zero K treatment on all indicators. Decreasing potassium appropriately (360 kg/hm^2) and postponing potassium application (in a ratio of basal fertilizer to topdressing fertilizer of 3 : 7) were advantagous. In specific, ① it improved the canopy structure and increased penetration of light to lower levels, narrowing the angles between leaf and stem of the middle leaves and of the plant as a whole, with a reduction of 1.76° and 2.58° respectively compared with high basal potassium treatment. Meanwhile, it shortened the internode length, which is conducive to improvement in the structure of the leaf. ② Increasing the proportion of potash top dressing made possible a distinct reduction in potash fertilizer input, but this measure did not have any effect on the potassium content in the middle and upper leaves in the later stage of growth (from vigorous growth to maturity), and chlorophyll content in the canopy increased with the increase in the proportion of top dressing. ③ At appropriate potash application levels, as top dressing proportions rose, nicotine content tended to decrease. ④ A potassium postponing regime with less basal application and more top-dressing was not only able to save 90 kg of potash per hectare, but also advantageous to nitrogen-potassium balance and late stage potassium effectiveness, ultimately achieving a balance between yield and quality and obtaining higher output value. [**Conclusions**] This study lays a foundation for the research on suitable application period and quantity of potassium fertilizer.

Key words Flue-cured tobacco; Potassium fertilizer; Canopy; Yield; Quality

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Tobacco is a potashphilous crop. Potassium is a significant quality factor in the growth of flue-cured tobacco, as well as the element which tobacco can absorb in the greatest quantities[1]. It plays a part in almost all material metabolism and energy metabolism, and has an important role in improving the growth and development of tobacco plants and the quality of tobacco leaves[2-3]. Potassium content is an important gauge of the internal quality and external appearance of flue-cured tobacco. The potassium content of tobacco abroad ranges from 40 to 60 g/kg. Although there is a requirement for the potassium content of high quality flue-cured tobacco to be at least 20 g/kg in China, it is still around 15 g/kg in most tobacco areas[4-6]. Flue-cured tobacco is supposed to be produced in volumes compatible with high quality. However, tobacco farmers want to achieve high volumes at low cost, and this often results in inappropriate fertilizing, with too much nitrogen and not enough potassium. For flue-cured tobacco under normal conditions, potassium absorption rises sharply with the onset of vigorous growth, reaching a peak when buds appear. When the buds are pinched off, it declines sharply, and then slower when it has sunk to a certain level[7-8]. Isotopic tracing shows flue-cured tobacco potassium absorption as rather low initially, reaching a peak 45 – 60 d after planting out, and declining rapidly after 60 d[9]. Moustakas *et al.* [10] also found that the greatest rate of absorption was reached 41 – 75 d after planting out, and the value declined greatly after that.

Materials and Methods

Testing ground

The experiment was carried out in 2023 in Miyi Tobacco Science and Technology Park, Sichuan Province. This park is located in Xinlong Village, Puwei Town, Miyi County, at an elevation of 1 727 m and at 101.97° E 27.06° N. In front of the testing ground is there a field of rape. The soil type is red soil, and the land type is dry farmland. The topsoil (0 – 20 mm) contains total nitrogen 1.24 g/kg, total potassium 1.27 g/kg, available phosphorus 14.59 mg/kg and available potassium 123.51 mg/kg, and organic matter 23.83g/kg, and has a pH of 5.7.

Experiment design

The experimental material was a new strain of flue-cured tobacco, JSZX-09-011F1. The planting density was 120 cm × 50 cm. Sowing was on February 25, and planting out was on May 6. Nitrogen fertilizer was applied at 90 kg/hm^2 and P_2O_5 at 75 kg/hm^2, and potassium fertilizer (K_2SO_4) was applied in accordance with the experiment design. Other field management followed the usual methods for large-field production of high-quality tobacco.

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The experiment adopted a split-plot design, with the amount of potassium in the main area, the ratio of basal fertilizer to top-dressing fertilizer in the deputy area. The test was repeated three times. Based on the preliminary results of the previous year's trial, four types of potassium fertilizer (K_2SO_4) regime were applied, high-level potassium, medium-level potassium, low-level potassium and zero potassium. K_0 was zero potassium, and K_1, K_2 and K_4 were corresponding to potassium, levels of 270, 360 and 450 kg/hm^2 (the norm in local practice), respectively. Under each regime, three following fertilizer application patterns were used: T_1 (with a ratio of basal fertilizer to topdressing fertilizer of 3 : 7), T_2 (with a ratio of 5 : 5, the local practice), and T_3 (with a ratio of 7 : 3). Top dressing was carried out 45 d after planting out.

Measurement methods

The following indexes were measured during June to October 2023.

Canopy structure index After pinching off, a crop canopy analyzer made by Sunscan of Canada was employed, and groups of tobacco plants of the same growth level were selected. In each block were established three sampling locations where light transmittance to the top and middle leaves and the base was recorded and a leaf area index was calculated. A metric ruler and protractor were used to measure plant height, leaf length and width, internode length and angle between leaf and stem.

Canopy physiological index A portable chlorophyll meter manufactured by Zhejiang Tuopu Instruments and a crop canopy analyzer made by Sunscan of Canada were used to determine the relative content of chlorophyll in each leaf (SPAD value) from the top to the bottom of the plant and the photosynthetic rate. In each block, five plants were chosen and the measurements were replicated three times. The measurements were made during the maturity of the leaves in each part.

Tobacco yield and output value indexes The indexes were calculated block by block. Mature leaves were tagged, collected and roasted, and then calculations were made under national grading standards for yield, output value, the proportion of top grade and upper middle grade leaves, and leaf unit weight.

Regular chemical composition measurement The field tagging mode was used. When the leaves were mature, they were collected in batches and roasted, and then graded according to the GB2635-92[13] standard for flue-cured tobacco, with leaves from the middle (C3F) and the upper (B2F) parts being selected as the samples for measurement. Meanwhile, three duplicate samples were mixed and kept on hand for examination. The regular chemical composition of the tobacco leaves was measured with an AAIII Continuous-Flow Analyzer using standard methods for "Tobacco and Tobacco Products". Mineral nutrients were determined by the dry-ashing method using an ICP-MPX spectrometer.

Data analysis

Microsoft Excel and SPSS Statistics 19.0 were used for the statistics and analysis work.

Results and Analysis

Vertical canopy structure changes

Plant morphology changes (height, internode length and the length and width of middle leaves) Table 1 shows that the height, internode length and the length and width of the middle leaves in the blocks under potassium treatment were consistently larger than in those without such treatment. With regard to the effect of potassium treatment on plant height, the quantity of potassium (K) did not play a significant role, but the different treatment methods (T) did have a distinct impact. The differences between K_1T_1, K_1T_2, and K_3T_1 were not significant, but they all differed significantly from other treatments, which indicates that the effectiveness of potassium fertilizer depends on the proportions of earlier and later applications, with an increase in top-dressing fertilizer promoting plant growth. In K_1T_2, K_3T_1 and K_1T_1, the plant height exceeded the zero potassium treatment by 11.18, 10.52 and 9.92 cm respectively. As for the effect of potassium treatment on the internode length, the difference between low-potassium and high-potassium treatment was not remarkable, whereas both were significantly different from medium-potassium treatment, with the internode length under medium potassium being relatively short. The different ways in which the potassium was applied had no significant impact on the internode length. Regarding the effects of potassium treatment on middle leaves, there was no significant difference between application regimes at medium potassium levels, but at low-potassium and high-potassium levels, they were distinctly different. Treatment K_2T_1 produced the longest and widest middle leaves. These results indicate that at different potassium levels, reducing the proportion of basal fertilizer and increasing the proportion of top dressing fertilizer serves to coordinate translocation, enhance photosynthesis, and promote the growth of tobacco leaves. Treatment K_2T_1 in the experiment produced moderate plant height, moderate internode length and maximum surface in the middle leaves.

Changes to canopy light penetration, stem to leaf angle and leaf area under different potassium fertilizer regimes Table 2 shows that there were no significant differences in the leaf area index of bottom leaves at low potassium levels, but at medium and high levels there were clear differences with different methods of application. At middle levels, K_2T_1 produced the largest leaf area, whereas at high levels, it was K_3T_3, and the K_2T_1 index exceeded K_3T_3 by 8.57%, a significant difference. For middle leaves the leaf area index did not show large differences at a low potassium level, but at medium and high levels, K_2T_1 and K_3T_3 showed a large difference from other treatments, exceeding zero potassium by 40.32% and 31.74%, respectively.

Increases of potassium (K) had little impact on leaf to stem angle or light transmittance. But under different fertilization methods (T), K_2T_1 and K_3T_3 were significantly different from the other treatments in terms of the leaf to stem angle at middle and bottom levels of the plant. In the moderate potassium fertilizer (K_2), the light transmittance lowest in both middle and bottom leaves, the different ratio of basal fertilizer to topdressing fertilizer had little impact on the light transmittance in both middle and bottom leaves, and the leaf area index was distinctly different. K_2T_1 produced the largest leaf area index in both middle and bottom leaves.

Therefore, the potassium treatment had a certain effect on the tobacco canopy structure. K_2T_1 had the largest stem to leaf angle in the middle leaves and the lowest light transmittance. K_1T_3 had the smallest stem to leaf angle in the middle leaves and the largest light transmittance. K_2T_1 had the largest leaf area index. It showed that with K_2T_1 treatment an appropriate level of potassium fertilizer and an appropriate fertilization method could adjust the group canopy structure to a certain extent, making the leaf blades from the middle upwards more vertical, which gave the lower leaves better access to light and increased light transmittance low down.

Table 1 Plant characteristics under different potassium fertilizer regimes

Treatment	Plant height // cm	Internode length // cm	Middle leaf	
			Length // cm	Width // cm
K_1T_1	117.87 ab	4.77 bc	67.27 b	25.27 b
K_1T_2	119.13 a	5.38 a	68.20 b	25.07 b
K_1T_3	117.07 b	5.01 ab	71.07 a	25.33 b
K_2T_1	115.00 c	4.36 c	71.87 a	28.53 a
K_2T_2	114.67 c	4.53 c	70.60 a	27.20 a
K_2T_3	114.75 c	4.34 c	71.80 a	27.40 a
K_3T_1	118.47 ab	4.76 bc	66.73 b	24.93 b
K_3T_2	115.20 c	5.01 ab	67.33 b	24.07 b
K_3T_3	115.07 c	4.66 bc	71.53 a	28.07 a
K_0	107.95	4.17	65.73	23.07

Values within a column followed by different letters are significantly different at $P<0.05$.

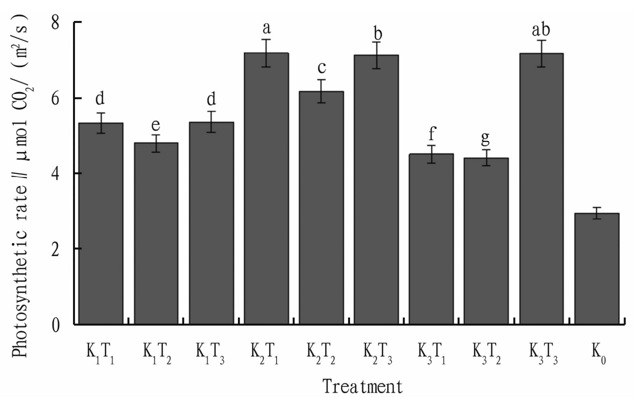
Table 2 Changes of canopy light transmittance, leaf angle, and LAI under different potassium fertilizer regimes

Treatment	Middle leaves			Bottom leaves		
	Leaf angle // °	Transmittance // %	Leaf area index	Leaf angle // °	Transmittance // %	Leaf area index
K_1T_1	84.47 c	17.87 a	3.71 cd	64.51 c	7.88 ab	2.71 def
K_1T_2	84.28 cd	17.95 a	3.65 cde	64.32 c	7.91 ab	2.65 ef
K_1T_3	83.71 d	18.14 a	3.45 e	64.55 c	7.82 b	2.75 cde
K_2T_1	88.71 a	16.42 b	4.42 a	68.72 a	6.41 c	3.42 a
K_2T_2	86.12 b	16.78 b	3.82 cd	66.14 b	6.68 c	2.82 cd
K_2T_3	86.52 b	16.65 b	3.87 c	66.53 b	6.61 c	2.87 c
K_3T_1	83.81 cd	18.11 a	3.58 de	63.82 c	8.14 a	2.58 fg
K_3T_2	84.52 c	17.86 a	3.75 cd	63.74 c	8.05 ab	2.45 g
K_3T_3	88.52 a	16.55 b	4.15 b	68.55 a	6.45 c	3.15 b
K_0	83.37	18.35	3.15	63.35 c	8.38	2.15

Values within a column followed by different letters are significantly different at $P<0.05$. K_0, K_1, K_2, K_3 represent K applied at 0, 270, 360, and 450 kg/hm^2, respectively. T_1, T_2 and T_3 indicate basal to topdressing fertilizer ratios of 3 : 7, 5 : 5 and 7 : 3, respectively.

Changes to canopy physiological indexes

Canopy photosynthetic rate changes under different potassium fertilizer regimes Fig. 1 indicates clearly that the canopy photosynthetic rate in each of the nine kinds of potassium fertilizer regimes was higher than in the zero-potassium regime. The three medium potassium (K_2) regimes produced a relatively high photosynthetic rate, and of the high potassium (K_3) regimes, K_3T_3 showed the highest photosynthetic rate. Under the same potassium level (K), an increase (T_1) or decrease (T_3) in top-dressing fertilizer produced a higher photosynthetic rate than the 50 : 50 proportion (T_2). K_2T_1, K_2T_3 and K_3T_3 achieved a high photosynthetic rate, indicating that the different potassium fertilization regimes have a certain influence on the mobility of potassium within flue-cured tobacco. In T_1 modes, more potassium was deployed in the physiological and biochemical development of the leaves. In T_3 modes, the high concentration of potassium in the roots inhibited the reflow of potassium, making the leaves retain a high potassium level, and thus promoting photosynthesis.



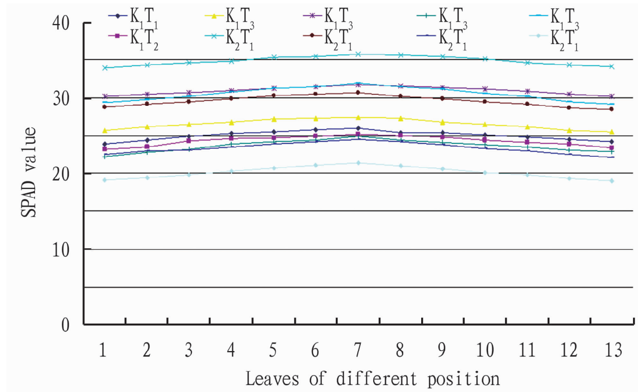
K_0, K_1, K_2, K_3 represent K applied at 0, 270, 360, and 450 kg/hm^2, respectively. T_1, T_2 and T_3 indicate basal to topdressing fertilizer ratios of 3 : 7, 5 : 5 and 7 : 3, respectively.

Fig. 1 Changes of photosynthetic rate under different potassium fertilizer regimes

Vertical changes of canopy chlorophyll content under different potassium fertilizer regimes As shown in Fig. 2, under all nine fertilization regimes the chlorophyll content in the middle leaves was higher than in the upper and lower leaf blades, and these leaves had the highest proportion of chlorophyll in the whole plant. It indicates that after pinching out of buds photosynthesis is stronger in the middle and upper parts and these parts are also more vigorous in growth. They are the main organ for the formation and accumulation of organic matter and play a decisive role in the ultimate yields of flue-cured tobacco. The relative chlorophyll content of the leaves in the entire plant under potassium treatment was higher than under zero-potassium treatment, and in later stages of growth leaves under zero-potassium treatment showed signs of aging, probably because there was insufficient potassium in the part of the plant above ground, and decline of the chlorophyll in the leaves impeded photosynthesis. Among all the potassium treatments, K_2T_1 produced the highest chlorophyll content, and the general trend under different potassium treatments was for leaf chlorophyll to increase as the proportion of top-dressing fertilizer increased. K_2T_1 and K_2T_2 produced the largest growth in chlorophyll content. It implies that proper application of potassium fertilizer and adjustment of the ratio of basal to topdressing fertilizer can not only save fertilizer but also help photosynthesis.

Yield, quality and economic traits under different potassium fertilizer regimes

Table 3 shows that differences in the yield per unit area of tobacco under different quantities of potassium and with different fertilizer application patterns were significant, and in output value, they were highly significant. However, there were no significant differences in the proportion of upper-medium tobacco and the weight per unit leaf. The ranking of yield and output value was $K_2 > K_1 > K_3$, with K_2T_2, K_2T_1 and K_1T_3 showing the highest figures. In terms of yield, these three ranked as $K_2T_2 > K_2T_1 > K_1T_3$, whereas in output value the ranking was $K_1T_3 > K_2T_1 > K_2T_2$. Evidently differences in potassium fertilizer regimes have a marked effect on the yield, quality and economic traits of flue-cured tobacco. Applying potassium fertilizer in the right quantities and using correct proportions of basal and top-dressing fertilizer would increase yield and output value, increase the proportion of upper-middle tobacco, and benefit the structure of the tobacco leaves, increasing unit weight. The results suggested that K_1T_3, K_2T_1 and K_2T_2 regimes produced better general economic outcomes.



K_0, K_1, K_2, K_3 represent K applied at 0, 270, 360, and 450 kg/hm^2, respectively. T_1, T_2 and T_3 indicate basal to topdressing fertilizer ratios of 3 : 7, 5 : 5 and 7 : 3, respectively.

Fig. 2 Relative chlorophyll content of canopy leaves under different potassium fertilizer regimes

Meanwhile, it could be seen that (within each K group) K_1T_3, K_2T_2 and K_3T_3 treatments all resulted in better performance in yield and output value, with upper-middle tobacco too appearing in significantly higher proportions than in other treatments. However, of these three only K_2T_2 stood out clearly in yield and K_1T_3 in output value, indicating that the way in which potassium fertilizer was applied had a greater impact than the quantity of potassium fertilizer used.

Table 3 Yield, quality and economic traits under different potassium fertilizer regimes

Treatment		Yield//kg/hm^2	Output//yuan/hm^2	The meso-scale tobacco//%	Single leaf weight//g
K_1T_1		1 875.45 c	44 977.07 bc	86.69 ab	8.85 b
K_1T_2		2 655.15 a	45 638.52 bc	78.01 b	9.87 ab
K_1T_3		2 725.73 a	62 609.83 a	93.14 a	10.19 ab
K_2T_1		2 729.70 a	51 898.74 b	91.65 a	9.54 ab
K_2T_2		2 770.95 a	49 615.22 bc	88.82 ab	9.75 ab
K_2T_3		2 225.40 bc	29 125.67 d	88.24 ab	9.63 ab
K_3T_1		2 684.40 a	44 309.31 c	91.31 a	8.87 b
K_3T_2		1 932.60 c	27 065.44 d	85.89 ab	11.02 a
K_3T_3		2 407.28 ab	44 697.63 bc	93.66 a	9.32 ab
K_0		1 817.59	26 733.46	80.98	8.19
F value	K	3.37	23.05**	1.42	0.03
	T	0.04	6.33**	3.94*	2.81
	K×T	16.58**	32.22**	1.38	1.22

Values within a column followed by different letters are significantly different at $P<0.05$. K_0, K_1, K_2, K_3 represent K applied at 0, 270, 360, and 450 kg/hm^2. T_1, T_2 and T_3 indicate basal to topdressing fertilizer ratios of 3 : 7, 5 : 5 and 7 : 3, respectively. K×T represents interaction between quantities of K and their application regimes. * and ** represent significant difference at 0.05 and 0.01 probability levels, respectively.

Regular chemical composition under different potassium fertilizer regimes

The regular chemical composition of flue-cured tobacco showed significant or highly significant differences under different potassium fertilizer regimes (Table 4 and Table 5). Analysis of carbohydrates showed the differences for total sugar, reduced sugar and starch reaching significant levels, with the reduced sugar index rather high under K_3T_1 and K_3T_3 and rather low under K_1T_3, K_2T_2 and K_2T_3, but otherwise remaining within an appropriate range (16% to 18%) with K_2T_1 and K_1T_1 most appropriate. Total nitrogen under all treatments was within a reasonable range for high quality tobacco (1.5% to 3%). There were significant differences in total potassium content, but no treatment produced the proportion acceptable for high-quality tobacco (> 3%). The nicotine content under all treatments was at an acceptable level for high-quality tobacco (1.5% to 3.5%). In general, the quantity of regular chemical constituents tended to increase with increases in topdressing. Bearing in mind that total sugar content tends to be high in this tobacco-growing region, the values for the sugar/nicotine and potassium/nicotine ratios would suggest that K_2T_1 K_2T_3 and K_2T_2 produced the most balanced chemical composition.

Table 4 Regular chemical composition of flue-cured tobacco leaf under different potassium fertilizer regimes

Treatment	Total nitrogen//%	Total potassium//%	Total sugar//%	Reducing sugar//%	Starch//%	Nicotine//%	Sugar/ nicotine	Potassium/ nicotine
K_1T_1	2.09 a	1.51 d	33.25 a	17.21 d	2.72 c	1.93 ab	17.24 b	0.78 de
K_1T_2	1.79 bc	1.21 g	21.35 e	14.73 e	3.34 b	1.42 f	15.15 c	0.86 cd
K_1T_3	1.72 c	1.22 g	26.73 c	9.08 g	3.34 b	2.01 a	13.31 d	0.61 f
K_2T_1	1.82 b	1.94 b	22.55 d	17.80 c	3.56 a	1.45 f	15.61 c	1.34 a
K_2T_2	1.48 e	1.46 e	22.17 d	9.32 g	2.59 cd	1.74 d	12.74 d	0.84 cd
K_2T_3	1.37 f	1.35 f	22.38 d	8.87 g	2.49 d	1.87 bc	11.97 d	0.72 e
K_3T_1	1.80 bc	1.99 a	33.33 a	22.62 a	3.55 a	1.84 bcd	18.11 b	1.08 b
K_3T_2	1.59 d	1.56 c	27.19 c	13.21 f	2.06 e	1.78 cd	15.28 c	0.88 c
K_3T_3	1.58 d	1.34 f	32.47 b	19.42 b	2.71 c	1.58 e	20.55 a	0.85 cd
K_0	1.41	0.18	16.52	7.31	2.36	1.22	13.54	0.97

Values within a column followed by different letters are significantly different at $P<0.05$. K_0, K_1, K_2, K_3 represent K applied at 0, 270, 360, and 450 kg/hm^2. T_1, T_2 and T_3 indicate basal to topdressing fertilizer ratios of 3 : 7, 5 : 5 and 7 : 3.

Table 5 F-test of interaction effects under different potassium fertilizer regimes on the contents of total potassium (tk), total sugar (ts), reducing sugar (rs), starch (s) and nicotine (n), ratio of total sugar to nicotine (sn) and total potassium to nicotine (kn) in flue-cured tobacco leaf

Item	Df	F_{tn}	F_{ts}	F_{rs}	F_s	F_n	F_{sn}	F_{nn}
K	2	418.96**	1276.50**	1454.73**	27.32**	5.13	78.11**	73.89**
T	2	1 037.30**	651.01**	2 005.47**	79.20**	15.41**	26.12**	158.68**
K × T	4	47.04**	205.22**	430.93**	98.31**	49.35**	23.31**	45.91**
Treatment	8	387.59**	584.49**	1 080.51**	75.79**	29.81**	37.71**	81.10**

K × T represents interaction between quantities of K and their application regimes. * and ** represent significant difference at 0.05 and 0.01 probability levels, respectively.

Discussion

Effects of different potassium fertilization regimes on canopy structure of flue-cured tobacco

There is little research on the influence of potassium fertilizer on canopy structure in tobacco plants, and previous researchers have mainly focused on such questions as changes in carbon and nitrogen metabolism, changes in enzyme activity, and changes in chlorophyll content[14-16]. This study showed that at a given potassium level, keeping basal fertilization low (T_1) promoted the growth of the tobacco plant, reduced the stem to leaf angle above the middle and made the stem to leaf angle in middle and lower parts of the plant 1.76° and 2.58° lower respectively than in plants treated with high basal fertilizer (T_3). Light transmittance in the middle and lower parts of the canopy also increased, and the general photosynthetic capacity of the group was consequently enhanced. Meanwhile, the plants tended to be more compact and better able to tolerate close planting, and leaf structure was improved. Finally, proper control of potassium in the early stages had a certain effect on the internode length. The average internode length from the middle downwards under regimes T_1, T_2 and T_3 was 4.63 , 4.97 and 4.67 cm, respectively. Achieving a suitable internode length makes the leaves in different parts mature more consistently. Evidently a fertilization regime which starts light and then supplements and which introduces potassium at a later stage helps to prevent potassium loss and lays a foundation for producing quantities consistent with quality.

The quantity of potassium fertilizer and the way in which it was applied had an effect on the canopy structure of the tobacco. K_2T_1 produced the largest stem to leaf angle in the middle leaves and the least light transmittance, and K_1T_3 produced the opposite. K_2T_1 showed the highest leaf area index. These results indicate that an appropriate level of potassium fertilizer applied in the right way, as under treatment K_2T_1, can adjust the group canopy structure within a certain range: the leaf blades in the middle and above tend to be more upright, giving the bottom leaves access to the light and increasing light transmittance low down. Therefore, while ensuring appropriate production levels, determining appropriate potassium fertilizer inputs and applying them rationally can improve the efficiency of fertilizer use, and help shape optimal tobacco canopy structure.

Potassium is an essential mineral for plants[17-19], and inhibition of photosynthesis caused by lack of potassium is a major factor affecting plant growth[20-21]. Lack of potassium reduces the synthesis of chlorophyll[20-22], and it restricts the net plant photosynthetic rate and increase of biomass. This study showed that for such indicators as length and width of middle tobacco leaves, leaf area index, photosynthetic rate, chlorophyll content and final yield, K_3 treatment was markedly inferior to K_2. Treatment K_2T_1 achieved the best yield and quality outcome, outperforming K_3T_1 by 1.69% in yield and 17.13% in output value but saving 90 kg/hm^2 in fertilizer. A study by Zhang *et al.* [19-21] suggests that, in a certain range, chlorophyll content and photosynthetic rate in tobacco leaves are positively correlated with the potassium content, which is consistent with the conclusion of this research. In our study, an appropriate reduction in the proportion of basal potassium fertilizer and the transfer of some potassium fertilizer to the later stages of cultivation did not decrease the chlorophyll content and the total potassium content in the dome leaf period, but instead enhanced the functionality of the leaves and enabled them to form a high-efficiency canopy structure. Therefore, potassium fertilizer should be applied in proper quantities and the proportion of top-dressing fertilizer should be suitably increased.

Effects of different potassium fertilization regimes on the regular chemical composition of flue-cured tobacco

Cigarette production practice shows that the aroma, taste and other intrinsic qualities of tobacco are to some extent determined by the quantity of nitrogen compounds, carbohydrates, polyphenols and other similar substances in the leaves, but are fundamentally determined by the balance of these various components. Generally speaking, the following ratios are thought to be ideal: total sugar to protein, (2-2.5) : 1; total sugar to nicotine, 10 : 1; total nitrogen to nicotine, 1 : 1; potassium to nicotine, 1 : (1-2); potassium to chlorine, over 4 : 1; tar to nicotine, under 10 : 1[22]. This study showed that the regular chemical components of tobacco tend to increase as the proportion of top-dressing potassium fertilizer increases, on the evidence of two indexes, the sugar to nicotine and potassium to nicotine ratios. Furthermore, taking into account the fact that the total sugar content in this tobacco area is on the high side, the chemical components were more balanced under K_2T_1, K_2T_3 and K_2T_2.

Regarding the influence of potassium on nicotine content, Tso[24] believed that there is no impact, and research conducted by Leggett and others showed that potassium has no significant effect on the total nitrogen and total alkaloid content[25]. This study also found that different quantities of potassium fertilizer have no significant effect on the nicotine content, but that different proportions of basal and top-dressing fertilizer do have a highly significant impact on the nicotine content. With an appropriate quantity of potassium (K_2), an increase in the proportion of fertilizer applied as top-dressing tends to reduce the nicotine content. Treatments K_2T_3, K_2T_2 and K_2T_1 showed differences at a significant level, with nicotine content decreasing progressively by 7.47% and 20.00%. Many other studies have suggested that increased potassium fertilizer can reduce the nicotine content of tobacco[26]. It is mainly the result of a dilution effect caused by the increase of potassium fertilizer leading to an increase in biomass[27], and is consistent with the results of this study.

The effect of different potassium fertilization regimes on economic traits of tobacco

Abundance of data suggest that phased application of potassium in top dressing is more effective than a single basal application[28-31]. For example, the sand culture experiment of Liu *et al.* [30] showed that the application of potassium to tobacco in the middle stage of growth had a strong effect on biomass and potassium content, whereas in the early stage it mainly influenced biomass and had little effect on potassium content, and in the late stage it mainly influenced potassium content and had little effect on biomass. This study is consistent with the results of earlier research. With different quantities of potassium (K_1, K_2 and K_3), the total potassium content of tobacco leaves differed markedly with different regimes of fertilizer application (T_1, T_2 and T_3). In other words, at a certain level of potassium fertilizer the potassium content of the plants tended to increase as the proportion applied as top-dressing increased.

Lin Kehui concluded that within a certain range increasing the amount of potassium fertilizer increased the potassium content of tobacco leaves, and that this potassium content was positively correlated with tobacco yield per hectare[32]. However, once potassium fertilizer exceeded suitable levels, further increases made no very clear difference to tobacco yield. A study by Zhao Jiuming indicated that improvement in quality could be achieved by potassium fertilization within a range of 80 to 130 kg/hm^2. From this study, it appears that a suitable quantity of potassium fertilizer (360 kg/hm^2) applied in a rational way (basal to top-dressing ratio of 3 : 7), helps to increase yield and output value, as well as the proportion of upper-middle tobacco, and to improve tobacco leaf structure, increasing unit weight per leaf. The way potassium fertilizer is applied is more important than its quantity.

Conclusions

An appropriate reduction in the quantity of potassium (360 kg/hm^2) along with an increase in the proportion of top-dressing fertilizer not only requires smaller potassium fertilizer inputs than traditional potassium fertilization methods (450 kg/hm^2) with better effects, but also does not impair the potassium content of upper leaves in the later stage of leaf growth (from vigorous growth to maturity), with a consequent effect on photosynthesis, yield and quality. An increase in the proportion of top-dressing fertilizer to 70% can reduce the stem to leaf angle in the plants from the middle upwards, making distribution of light within the canopy more even. A reduction in the proportion of basal fertilizer can shorten internode length and optimize leaf structure. At an appropriate level of potassium fertilizer, the nicotine content tends to decline as the proportion of top-dressing fertilizer increases. A potassium postponing regime with less basal fertilizer and more top-dressing is advantageous to the nitrogen-potassium balance and to the effectiveness of potassium in the later stage of growth. Ultimately, a balance between yield and quality in tobacco production can be achieved, thereby improving output value.

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