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Full Length Article

Straw Return with Dolomite Application Increase Flue-Cured Tobacco Leaf Yield and Quality

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Abstract

Straw return and liming are often applied to improve soil fertility and crop yield on acidic soils. Albeit, there are several studies for the effect of these practices on soil physical and chemical characteristics and crop plant growth, it is still unclear whether or how straw return and liming affect tobacco yield and quality. A field experiment was conducted from 2015 to 2018 to study the effect of both tobacco straw return and dolomite application and their interaction on soil pH, yield, quality and chemical elements of flue-cured tobacco leaf. Results showed that compared with the CK, straw return with liming (St + L) or with dolomite (St + D) increased trade yield by 21.4 and 11.7%, and the market value increased by 33.7 and 24.7% in 2018, respectively. The St + L and St + D significantly increased the smoking quality and K concentration of cured leaves compared to the CK, moreover, the reducing sugars in St + D (26.7–27.0%) were significantly higher than other treatments. Since 2016, St + D significantly increased the Mg concentration of leaves compared with all other treatments. The Mg concentration of leaves in St + D increased with the increase of treatment time, while decreased in St + L. Therefore, it is suggested that dolomite should be applied with straw return to enhanced tobacco leaf quality, particularly for Mg concentration and reducing sugars content in tobacco-rice cropping system.

Keywords: Straw; Dolomite; Flue-cured tobacco; Magnesium; Soil exchangeable calcium

Introduction

Tobacco (*Nicotiana tabacum* L.) is an important industrial crop for many countries (Bilalis *et al.* 2015; Guang *et al.* 2019). Especially, China's flue-cured tobacco planting area is about one-third of the worldwide and the tobacco industry nets accounts for about 10% of the national tax income (Zou *et al.* 2018). Tobacco also plays an important social and economic role, being main source of income for many families, due to the high quality and good characteristics of tobacco leaves in Anhui province (Dong *et al.* 2015). Flue-cured tobacco region in Anhui is typically multiple cropping of tobacco-rice, which is one of the representatives producing areas of characteristic and high quality tobacco leaves (Dong *et al.* 2015; Zhang *et al.* 2016). However, tobacco leaf quality and farmers' income have potentially declined with the increase of continuous cropping years of tobacco-rice (Jin *et al.* 2014; Zhang *et al.* 2016).

Tobacco-rice cropping system is special agricultural system that only occurs in some southern provinces of China such as Anhui, Hunan, Jiangxi, Fujian, Guangdong, Guangxi, Guizhou and Yunnan, with a planting area of 300, 000 ha^{-1} which accounts for nearly 30% of the tobacco planting area in China (Zhang *et al.* 2015; Jiang *et al.* 2016). The soils of tobacco-rice cropping system are a typical paddy soil in Anhui province, most of which is acid with a pH lower than 5.5 (Jiang *et al.* 2015). Moreover, soil acidification can be accelerated by intensive farming and overuse of chemical fertilizers in intensive farmland, including tobacco-rice field (Karaivazoglou *et al.* 2007; Jiang *et al.* 2015; Kunhikrishnan *et al.* 2016). Dolomite is a common practice to ameliorate acid soils and widely applied to tobacco-rice field in southern China (Jiang *et al.* 2015; Zou *et al.* 2018). The application of dolomite is a conventional technique for alleviating soil acidification in tobacco-rice cropping system (Jiang *et al.* 2015). Our previous study found that soil pH was increased by 0.11 units by the application of dolomite in flue-cured tobacco field (Jiang *et al.* 2015). However, research on the effects of dolomite on tobacco growth, leaf yield and quality in tobacco-rice cropping system is still limited.

Tobacco straw is an important organic resource, and the total annual yields averaged 8–10 Mt in China (Liu *et al.* 2017). Previous studies found that the potassium (K) of tobacco straw could reach 20 g K_2O kg^{-1}, and the nitrogen (N) and phosphorus (P) was about 14 g N kg^{-1}, and 16.9 g P_2O_5 kg^{-1}, respectively (Xiao *et al.* 2008; Jiang *et al.* 2016; Liu *et al.* 2017). Several studies have found that straw return

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could increase crop yield due to nutrient replenishment and improved soil fertility (Huang *et al.* 2013; Murphy *et al.* 2016; Liao *et al.* 2018). Therefore, as one of the renewable resources, the reasonable and effective use of tobacco straw is getting more and more attention. After the harvest of tobacco leaves, the tobacco straws were incorporated by a rotary cultivator cut into 10–15 cm pieces before rice transplanting (Jiang *et al.* 2016; Liu *et al.* 2017). The decomposition and nutrient release of tobacco straw under the condition of returning to the field have been demonstrated, and it was also found that the dolomite could accelerate the decomposition of tobacco straw (Jiang *et al.* 2016; Liu *et al.* 2017). However, few studies have been conducted on how tobacco straw return and dolomite affect soil pH, tobacco leaf yield and quality. Therefore, in this study, a field experiment of tobacco straw return and dolomite application in tobacco-rice cropping system were carried out during 2015–2018. The objective was to determine the effect of both tobacco straw return, dolomite application and their interaction on soil pH, yield, quality and chemical characteristics of flue-cured tobacco leaf.

Materials and Methods

Site description, soil properties and weather conditions

The field experiments were conducted from 2015 to 2018 at a famous tobacco planting area in the south of Anhui Province, China. The cropping system consists of tobacco (March to July) and rice (July to November). The soil is paddy field had an initial pH 5.5, organic matter 22.9 g kg^{-1}, total N 1.71 g kg^{-1}, available N 171.7 mg kg^{-1}, Olsen-P 36.5 mg kg^{-1}, and available K 209.3 mg kg^{-1} in the 0–20 cm soil layer prior to the experiment. The region is considered to have a subtropical, humid monsoon climate with an average annual air temperature of 16.9°C and mean annual precipitation of 1554 mm.

Experimental design and farm management

Four treatments were designed as follows: control (tobacco straw removed, CK), tobacco straw return (St), tobacco straw return with dolomite (St + D), and tobacco straw return with lime (St + L). Each treatment was replicated for three times, resulting in 12 plots each with an individual area of 36 m^2 (3.6 m × 10 m). In order to prevent the flow of water and fertilizer, four stringent ridges (30 cm in height, and 30 cm in width) were built around each plot, and each plot was equipped with a separate water inlet and outlet. For all straw return treatments, the tobacco straws were incorporated by a rotary cultivator cut into 10–15 cm pieces after the harvested of tobacco leaves in early July in 2014, 2015, 2016 and 2017. The lime and dolomite were broadcasted uniformly before the straws returned at a rate of 1.5 t ha^{-1}. For the CK, the tobacco straws were removed from the plot. The lime was used in the form of calcitic lime (Ca 396 g kg^{-1} and Mg 2.5 g kg^{-1}). The dolomite was applied as a fine powder < 0.3 mm, with Ca 220 g kg^{-1} and Mg 124 g kg^{-1}. Fertilizers were consisted of 115 kg N ha^{-1}, 180 kg P_2O_5 ha^{-1} and 375 kg K_2O ha^{-1} for flue-cured tobacco. The commercial fertilizers used were compound fertilizer for tobacco (N: P: K 9–13.5–22.5), superphosphate (0–15–0), potassium sulfate (0–0–50), and potassium nitrate (13.5–0–46). All the fertilizers were applied one day before transplanting of tobacco seedlings.

The tobacco variety used was flue-cured tobacco (*Nicotiana tabacum* L.) "Yunyan 87", the most popular in the region. The inter-rows were 120 cm wide and plants were spaced 50 cm apart in the rows (16,667 plants ha^{-1}). Seedlings were transplanted during the sec half of March in each experimental year. Irrigation, pesticide and herbicide applications were the same for all treatments and recommended for flue-cured tobacco in the area by Chizhou Tobacco Company of Anhui Province. The plant was topped (by removing the tobacco flowers) at during the period 60–70 days after transplanting, and the unproductive leaves (suckering) was removed manually.

Crop and soil analysis

Trade yield and market value: All plants were harvested five times by hand at 7- or 8-day intervals, by removing three to five leaves each time, starting 70–80 days after transplanting. The leaves were cured immediately after harvest in a flue-curing barn for flue-cured tobacco. The gross yield was measured at a 17% moisture content of the cured leaves, and the leaves were divided into commercial (trade yield) and noncommercial fractions, then the trade yield and market value were calculated.

Appearance Quality and Smoking Quality: Appearance quality of the commercial leaves was graded using a scale from 1 to 10 (quality index) by estimating and grading visual and physical characteristics including cured leaf color, maturity, body, leaf structure, oil, color intensity (Karaivazoglou *et al.* 2007). Smoking quality was graded using a scale from 1 to 10 (quality index) by evaluating and grading the smoking characteristics such as aroma quality and quantity, offensive odor, physiological strength, irritancy, comfortable aftertaste, sweet, dry sense, and moisturizing mellow (Jin *et al.* 2014).

Leaf sample analysis: Twenty leaves were randomly selected from the commercial leaves for chemical measurements. Samples were dried at 70°C for 48 h, to constant dry weight, and milled into powder for analysis. The samples were digested using the H_2SO_4-H_2O_2 method, and N, K, Ca and Mg were determined according to the method of Shao *et al.* (2012) and Tang *et al.* (2013). Nicotine and reducing sugars were measured by Continuous Flow Analysis (Karaivazoglou *et al.* 2007; Guo *et al.* 2013).

Soil analysis: Before the experiment, a 0–20 cm soil layer sample was collected to determine the basic fertility. After the harvest of tobacco leaf for each year, soil samples (0-20 cm) were collected from 12 plots for chemical properties analysis. Soil pH, alkali-hydrolyzed N, available K, exchangeable Ca and Mg were determined according to the method of Shao *et al.* (2012) and Tang *et al.* (2013).

Statistical analysis

Statistical analyses were performed using one-way ANOVA with S.P.S.S. 19.0 (S.P.S.S. Inc., Chicago, IL, U.S.A.). The treatments were compared by the method of least significance difference (LSD) test at $P < 5\%$.

Results

Cured leaf trade yield and market value

Straw return and liming had a significant effect on the trade yield and market value of cured tobacco leaves during the experimental years (Fig. 1). Trade yield was not affected by lime and straw retention in 2015 and 2017, but significantly affected by lime in both 2016 and 2018. Similarly, market value was not affected by lime and straw retention in 2015, but significantly increased by lime since 2016, and also increased by straw retention in 2018. Compared with the CK, St + L increased trade yield by 8.0, 7.8 and 21.4% in 2016, 2017 and 2018, respectively, while St + D and St treatments increased trade yield by 16.1 and 11.7% in 2018, respectively. Compared with the CK, St + L and St + D increased market value of cured leaves by 33.7 and 24.7% in 2018. Moreover, the market value of cured leaves in St + L was 8.7% higher than in St treatments in 2018. In general, trade yield and market value of cured leaves were both in the following order: St + L > St + D > St > CK.

Appearance quality and smoking quality

Straw retention and liming had significant positive effect on the appearance quality and smoking quality index of cured leaves (Fig. 2). However, the appearance quality of cured leaves did not show a significant difference among the St, St + D and St + L treatments except in 2017. The St + L and St + D significantly increased the smoking quality of cured leaves compared to the CK and St in 2017 and 2018. However, for all treatments, the smoking quality of cured leaves was decreased with the increase of planting time.

Chemical characteristics of cured leaves

The N and nicotine contents of the cured leaves in the first (2015) and sec (2016) year showed no significant difference among all treatments (Table 1). However, compared with the CK, the St, St + D and St + L treatments increased the N content by 21.5, 21.5 and 19.8% in 2017, and by 14.8, 17.2 and 18.9% in 2018, respectively. Similarly, the St, St + D and St + L treatments increased the nicotine content by 10.9, 13.0 and 13.8% in 2017, and by 10.4, 7.6 and 9.0%, in 2018, respectively. Liming had a statistically significant increasing effect on the reducing sugars of the cured leaf. The reducing sugars in the first (2015) year showed no significant difference among all treatments. However, after two years, the reducing sugars in St + D (26.7–27.0%) were significantly higher than other treatments (23.4–24.5%).

The K concentration of cured leaves ranged from 1.69 to 2.22%, and decreased by increasing the year of cultivation (Table 2). However, the K concentration was significantly increased by liming and straw retention after two years treatments. Compared with the CK, the K concentration of cured leaves for the St, St + D and St + L treatments were significantly increased by 16.5, 14.3 and 14.8% in 2016, respectively. However, there was no significant difference of K concentration of cured leaves among St, St + D and St + L.

Lime application had significant positive effect on Ca concentration of cured leaves (Table 2). In 2016, 2017 and 2018, the treatments St + L and St + D achieved significantly higher Ca concentration in leaves compared to CK. In both 2017 and 2018, the highest Ca concentration in leaves was observed in treatment St + L (23.68 and 24.79%), which was significantly higher compared to all other treatments. The Ca concentration of cured leaves was significantly higher in treatment St + L compared to St + D in both 2017 and 2018, but not in both 2015 and 2016. There was no significant difference in Ca concentration in leaves between the treatment CK and St.

The treatment St + D achieved the highest Mg concentration in leaves during the experiment, with significantly higher Mg concentration than all other treatments in 2016, 2017 and 2018 (Table 2). There was no significant difference in Mg concentration between the CK and St during the experiment. The Mg concentration of leaves in St + D increased with the increase of treatment time, while decreased in St + L during the experimentation period. Moreover, since 2016, St + D significantly increased the Mg content of leaves compared with all other treatments. The lowest Mg content of leaves was observed for St + L, that were significantly lower compared to treatments St + D and St in both 2017 and 2018.

Soil pH

Lime application had significant positive effect on soil pH (Fig. 3). The soil pH of St + L and St + D was 5.61 and 5.57 in 2015, which increased to 6.53 and 6.39 in 2018, respectively. Since 2017, St + L and St + D treatment resulted in significant higher soil pH compared with the treatments CK and St. However, straw return alone (St) did not significant affect the soil pH for two years application. In general, the soil pH was in the following order: St + L ≥ St + D > St ≥ CK.

Table 1: Effect of liming and straw returning on total nitrogen, nicotine and reducing sugars content of tobacco leaves

Treatments	Total nitrogen content (%)				Nicotine content (%)				Reducing sugars (%)			
	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018
CK	1.71 a	1.40 a	1.21 b	1.22 b	1.69 a	1.54 a	1.38 b	1.44 b	27.9 a	28.2 b	23.4 b	24.3 bc
St	1.69 a	1.46 a	1.47 a	1.40 a	1.79 a	1.56 a	1.53 a	1.59 a	28.0 a	28.6 ab	23.9 b	23.5 c
St + D	1.72 a	1.56 a	1.47 a	1.43 a	1.83 a	1.62 a	1.56 a	1.55 a	29.1 a	29.6 a	26.7 a	27.0 a
St + L	1.76 a	1.49 a	1.45 a	1.45 a	1.83 a	1.71 a	1.57 a	1.57 a	27.7 a	27.7 b	24.4 b	24.5 b

Means sharing different letters, within a column, differ significantly from each other at $P < 0.05$
Here CK, St, St + D and St + L are respectively tobacco straw removed, tobacco straw return, tobacco straw return with dolomite, tobacco straw return with lime

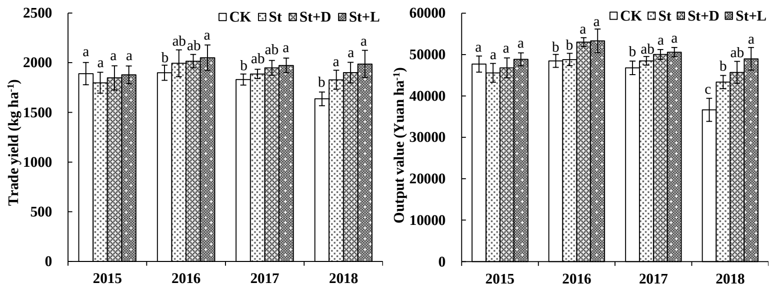

Fig. 1: Effect of straw return and liming on trade yield and output value of tobacco leaves (mean ± SD)
Here CK, St, St + D and St + L are respectively tobacco straw removed, tobacco straw return, tobacco straw return with dolomite, tobacco straw return with lime
Columns with different lowercase letters indicate a significant difference for different year ($P < 0.05$)

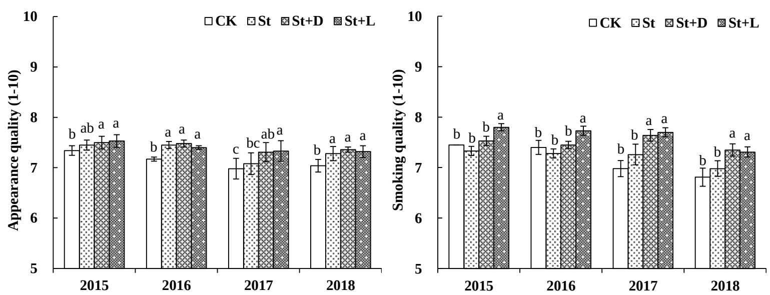

Fig. 2: Effect of straw return and liming on appearance quality and smoking quality of tobacco leaves (mean ± SD)
Here CK, St, St + D and St + L are respectively tobacco straw removed, tobacco straw return, tobacco straw return with dolomite, tobacco straw return with lime
Columns with different lowercase letters indicate a significant difference for different year ($P < 0.05$)

Soil nitrogen, potassium, calcium and magnesium content

Straw return significantly increased the soil alkaline hydrolyzable-N in 2018 (Table 3). However, no significant effect of liming was observed for soil alkaline hydrolyzable-N during the experiment. The available K content in soil was the lowest in treatment CK among all the treatments in all four years. In 2015 and 2016, there was no significant difference in available K content among all the treatments. In both 2017 and 2018, the highest available K content was determined in treatment St (239.6 and 319.4 mg kg^{-1}), which was significantly higher compared to treatment CK, but not to the treatments St + D and St + L. Straw retention significantly increased the soil available K content after the three year experiment.

The highest exchangeable Ca content of soil was observed in the St + L treatment, which was 1540.1 mg kg^{-1} in 2017 and 1813.4 mg kg^{-1} in 2018 (Table 4). The exchangeable Ca content of soil in the St + L was 30.6, 57.1 and 65.0% higher than in the St + D, St and CK treatments in 2018. Similar, the Ca content of soil in the St + D was 20.3 and 26.3% higher than in the St and CK treatments in 2018. The exchangeable Ca content of soil in both St + L and St + D increased with the increase of treatment time during the experimentation period. Treatment St + D achieved a significantly higher exchangeable Mg content of soil compared to all other treatments in 2016, 2017 and 2018, and exchangeable Mg content of soil in St + D was increased with the increase of treatment time. However, there was no significant difference in exchangeable Mg content of soil among the treatments CK, St and St + L for all years.

Discussion

In this study, liming significantly enhanced leaves yield of flue-cured tobacco on an acidic soil also reported in previous studies (Karaivazoglou *et al.* 2007; Jiang *et al.* 2015; Pang *et al.* 2019). The improvement in soil pH of

Table 2: Effect of liming and straw return on K, Ca and Mg concentration of tobacco leaves

Treatments	K concentration (g kg^{-1})				Ca concentration (g kg^{-1})				Mg concentration (g kg^{-1})			
	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018
CK	20.1 a	18.2 b	17.7 b	16.9 b	18.40 b	18.14b	18.19c	18.23c	2.41 a	2.28 b	2.11bc	1.97bc
St	21.8 a	21.2 a	21.0 a	20.4 a	19.09ab	19.38ab	19.30c	19.82c	2.45 a	2.39 b	2.36 b	2.21 b
St + D	22.0 a	20.8 a	20.7 a	19.5 a	19.13ab	20.86 a	21.46b	22.48b	2.48 a	2.83 a	2.98 a	3.06 a
St + L	22.2 a	20.9 a	20.5 a	19.2 a	19.71 a	21.80 a	23.68a	24.79a	2.39 a	2.24 b	2.02 c	1.76 c

Means sharing different letters, within a column, differ significantly from each other at $P < 0.05$
Here CK, St, St + D and St + L are respectively tobacco straw removed, tobacco straw return, tobacco straw return with dolomite, tobacco straw return with lime

Table 3: Effect of liming and straw return on alkaline hydrolyzable-N, and available K content of soil

Treatments	Alkaline hydrolyzable-N content (mg kg^{-1})				Available K content (mg kg^{-1})			
	2015	2016	2017	2018	2015	2016	2017	2018
CK	133.0 a	131.0 a	119.4 a	110.5 b	181.7 a	184.2 a	168.3 b	216.8 b
St	139.9 a	143.9 a	137.1 a	136.2 a	194.6 a	211.2 a	239.6 a	319.4 a
St + D	142.2 a	137.2 a	132.9 a	129.8 a	191.9 a	205.0 a	206.2 ab	288.7 a
St + L	137.9 a	139.7 a	133.2 a	134.5 a	195.5 a	190.9 a	207.4 ab	281.3 a

Means sharing different letters, within a column, differ significantly from each other at $P < 0.05$
Here CK, St, St + D and St + L are respectively tobacco straw removed, tobacco straw return, tobacco straw return with dolomite, tobacco straw return with lime

Table 4: Effect of liming and straw return on exchangeable Ca and Mg content of soil

Treatments	Exchangeable Ca content (mg kg^{-1})				Exchangeable Mg content (mg kg^{-1})			
	2015	2016	2017	2018	2015	2016	2017	2018
CK	956.7 a	996.6 b	1039.9 b	1099.3 c	137.7 a	127.0 b	141.2 b	150.1 b
St	971.5 a	1030.2 b	1112.3 b	1154.3 c	143.8 a	138.7 b	149.5 b	167.1 b
St + D	1077.4 a	1087.9 ab	1235.4 b	1388.7 b	159.1 a	196.7 a	217.3 a	310.9 a
St + L	1098.7 a	1283.7 a	1540.1 a	1813.4 a	132.3 a	144.0 b	144.1 b	169.8 b

Means sharing different letters, within a column, differ significantly from each other at $P < 0.05$
Here CK, St, St + D and St + L are respectively tobacco straw removed, tobacco straw return, tobacco straw return with dolomite, tobacco straw return with lime

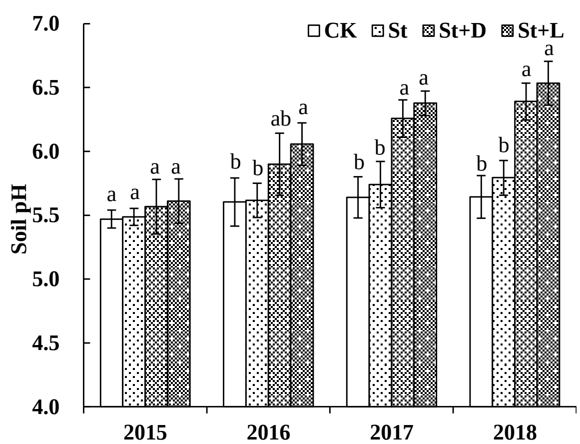

Fig. 3: Effect of liming and straw return on soil pH (mean ± SD)
Here CK, St, St + D and St + L are respectively tobacco straw removed, tobacco straw return, tobacco straw return with dolomite, tobacco straw return with lime
Columns with different lowercase letters indicate a significant difference for different year ($P < 0.05$)

lime and dolomite treatment probably increased the growth, yield and quality of tobacco. Karaivazoglou *et al.* (2007) also found an increase in yield of tobacco leaves in a field experiment limed with 0 to 3 t $Ca(OH)_2$ ha^{-1}. Similarly, in our previous study found significant yield increases of flue-cured tobacco on acidic soil, after the application of 1.5 t ($Ca(OH)_2$ ha^{-1}, which resulted in a pH increase from 5.3 to 5.8 (Jiang *et al.* 2015). Liming and dolomite also improved the smoking quality of cured tobacco leaf. Karaivazoglou *et al.* (2007) found that the quality of cured leaf was significantly increased from 6.7 to 7.2 by grade indices the application of hydrated lime ($Ca(OH)_2$). Jiang *et al.* (2015) found that N from tobacco straw is released during tobacco season, and its supply for high quality tobacco leaves was excessive. It was also reported that straw retention improved soil N supply, stimulated the growth of tobacco and increased the yield of cured leaf (Zhou *et al.* 2016; Tan *et al.* 2018; Wang *et al.* 2018).

Straw return increased leaf K concentration on average from 18.2to 20.9 g kg^{-1} (14% increase). Wang *et al.* (2018) found that wheat straw return significantly increased K concentration of middle and upper leaves by 8.39 and

22.63%, respectively. The increase of leaf K concentration under straw retention is primarily due to straw return significantly increased soil available K content (Li *et al.* 2014; Jiang *et al.* 2015) and enhanced the total amount of K uptake by plant (Bai *et al.* 2015). Moreover, previous research also showed that straw returned to the field can partially counterbalance the total K_2O consumption (Jiang *et al.* 2015; Yin *et al.* 2018a). Therefore, straw return has a great potential to reduce the use of chemical potassium fertilizer in China (Yin *et al.* 2018b). Liming increased 13–25% leaf Ca concentration of flue-cured tobacco after 4 years. The lower K content of leaves in limed treatments maybe due to the competition between K and Ca in their uptake by tobacco plants (Karaivazoglou *et al.* 2007; Duan *et al.* 2010). We found that the exchangeable Ca concentration of soil was significantly increased by 29 and 65% in lime application for 2 and 4 consecutive years. The exchangeable Ca of soil is an important source of calcium in tobacco, which also increased tobacco leaves Ca (Liu *et al.* 2017). In the study, the available potassium content was slightly decreased by the liming for two consecutive years even though there was no statistically significant difference. Karaivazoglou *et al.* (2007) reported that leaf K concentration was significantly decreased by 10 and 12% under the application of 1.5 and 3.0 t ha^{-1} $Ca(OH)_2$ in flue-cured tobacco. However, Wei *et al.* (2011) reported that calcium application improved the potassium uptake and increased the potassium content in flue-cured tobacco leaves. Therefore, liming may intensify K deficiency if low or no K fertilizer is applied. In general, high quality tobacco leaves require K concentration greater than 20 g kg^{-1}. Therefore, to increase the K concentration of tobacco leaves, more potassium fertilizer may need to be applied in this study area.

In addition, liming significantly decreased leaf Mg concentration from 2.36 to 2.02 g kg^{-1} in 2017 and from 2.21 to 1.76 g kg^{-1} in 2018. The lower leaf Mg concentration in limed treatments was probably due to the competition between Ca and Mg in their uptake. Previous study also showed that increasing Ca application caused a gradual decline in Mg concentration in cured tobacco leaves (López-Lefebre *et al.* 2001). Duan *et al.* (2010) reported that reduced Ca^{2+}/Mg^{2+} resulted in the improvement of Mg uptake and increased leaf Mg concentration. The lower leaf Mg concentration in limed treatments was probably due to the competition between Ca and Mg in their uptake (Liu *et al.* 2017), which found that Mg concentration in leaf was decreased with the increase of soil exchangeable Ca. In contrast, the dolomite significantly increased leaf Mg concentration by 18% after 2 years compared with the straw retention. The increase of leaf Mg concentration could be explained by the dolomite powder containing a lot of Mg (124.3 g kg^{-1}) in this study. Dolomite powder has significantly effect on increasing the Mg concentration in tobacco leaves, and improved the smoking quality of cured tobacco leaf. Moreover, straw return significantly increased the concentration of K but hardly significantly changed the concentrations of Ca and Mg in cured leaf. Moreover, the soil exchangeable Ca and Mg content was slightly affected by the straw retention. Therefore, more attention should be paid to investigate how long-term straw retention influences soil exchangeable Ca and Mg content and their concentration in plant tissue. And further research is needed to illuminate the Ca and Mg release and adsorption on tobacco straw residue.

Tobacco quality is a complex combination of visual, physical and chemical characteristics of cured leaves (Bilalis *et al.* 2015; Lin and Zhang 2016). Among them, traits including nicotine content, reducing sugars concentration and their ratio substantially affect the quality of tobacco leaf (Bilalis *et al.* 2015). The present study results showed that nicotine content was significantly increased by 13% for three years of straw retention (Table 1). The percentage of nicotine is one of the most important traits of tobacco (Çakir and Çebi 2010; Yin *et al.* 2018). It has been established that nicotine content of flue-cured tobacco leaf should be 0.3–3%, preferably around 2.95%, though nowadays taking into account the harmful effects of nicotine on the health of smokers, great attention is given to searching ways to decrease nicotine content to around 1% (Çakir and Çebi 2010; Shi *et al.* 2018). Reducing sugars concentration is also an indicator of smoking quality (Shao *et al.* 2011; Bilalis *et al.* 2015). Among other factors, cultivar may dramatically affect the levels of sugars in tobacco leaf (Bilalis *et al.* 2015; Gao *et al.* 2019). In this study, dolomite significantly increased the reducing sugar content of tobacco leaf after two years continuous cropping (Table 1). However, the straw return had no significant effect on reducing sugar, confirming the important role of dolomite on the quality parameters of tobacco content of tobacco leaf.

Conclusion

In a four-year experiment, it was determined the effects of straw return and liming on soil pH, flue-cured tobacco yield and quality. Both liming and straw return significantly increased the trade yield and market value of cured tobacco leaves. Dolomite application increased K concentration and smoking quality of tobacco leaves. Furthermore, dolomite increased reducing sugars content and Mg concentration of tobacco leaves. Therefore, it was suggested that dolomite should be applied with straw return to enhanced tobacco leaf quality, particularly for Mg concentration and reducing sugars content in tobacco-rice cropping system in southern China.

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Author Contributions

CQ Jiang and CL Zu designed the study; CQ Jiang, J Shen and YF Yang performed the experiments, collected and analyzed data; CQ Jiang and CL Zu wrote the and revised the manuscript." add after the Acknowledgments

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