OPTIMAL LIME APPLICATION RATES FOR AMELIORATING ACIDIC SOILS AND IMPROVING THE YIELD AND QUALITY OF TOBACCO LEAVES

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Abstract. Liming is a common practice for improving plant growth and yield on acidic soils. However, knowledge is still limited on the effect of liming on tobacco growth and leaf quality planted on acidic soil. In this study, effects of lime (Ca(OH)₂) (0, 0.75, 1.5 and 3 t ha⁻¹) on soil nutrient status (Ca²⁺ and Mg²⁺ in particular), growth, nutrient accumulation and quality of flue-cured tobacco was investigated in an acidic soil located in Anhui province, China. The results showed that liming significantly increased soil pH both 30 days after transplanting and after the harvest of the tobacco. In comparison with CK (no lime application), liming at a rate of 1.5 t ha⁻¹ increased leaf number and leaf dry weight by 15% and 11%, and enhanced the appearance and smoking quality of cured leaves by 7% and 9%, respectively. Moreover, liming significantly increased calcium concentration, while decreased nitrogen and magnesium concentration in the cured leaves. The increase in cured leaf quality was attributed to the improvement of chemical composition, particularly the increase in reducing sugar content. Together, our results suggest that Ca(OH)₂ application at a rate of 1.5 t ha⁻¹ may alleviate soil acidification and improve yield and quality of flue-cured tobacco in Anhui province, China.

Keywords: flue-cured tobacco, soil acidity, calcium, cured leaves quality, soil improvement

Introduction

Soil acidity is a serious limitation to plant growth and crop production in many regions of the world, since about 40-50% of the world’s arable soils are acidic (Kochian et al., 2015). Extreme acidity in subsoil (pH <5.0) limits plant growth and development, which is particularly harmful to root growth and function, and therefore inhibits root water and nutrient acquisition (Lynch and Wojciechowski, 2015; Wang et al., 2017). In less acidic soils (pH >5.0), the inhibition of plant growth and yield is more likely due to nutrient deficiencies and toxicities (Karaivazoglou et al., 2007; Hue, 2011). However, these inhibitions for plants may act independently or commonly work together (Karaivazoglou et al., 2007; Kochian et al., 2015). There are various causes for soil acidification, and excess nitrogen (N) fertilizer application has become a major cause in agricultural soils (Guo et al., 2010; Qu et al., 2013; Shaaban et al., 2015). Most of the tobacco (Nicotiana tabacum L.) fields have been affected by acidification due to the intensive cropping and excessive N fertilizer inputs in Anhui province, China (Zhang et al., 2014; Jiang et al., 2015a). Therefore, it is imperative to ameliorate acid soils and improve the yield and quality of tobacco leaves in these areas. However, optimal measure for ameliorating acid soils in tobacco growing area is still lacking in Anhui province at present.
Considerable measures have been made to ameliorate acid soils, improve crop yield and quality, such as lime application (Jiang et al., 2015a; Shaaban et al., 2015; Kunhikrishnan et al., 2016), straw retention (Liao et al., 2018), biochar application (Tarin et al., 2019), green manure and biological organic fertilizer application (Deng et al., 2019). Traditionally, surface application of lime materials (including lime, calcite and dolomite) is one of the most common measures to overcome the problems associated with soil acidity (Shaaban et al., 2014; Kunhikrishnan et al., 2016). Previous studies have shown that lime application increases soil pH, improves plant growth and leaf yield of tobacco (Karaivazoglou et al., 2007; Jiang et al., 2015a; Deng et al., 2019). Karaivazoglou et al. (2007) reported that hydrated lime (Ca(OH)$_2$) application at a rate of 3 t ha$^{-1}$ may alleviate soil acidification and increase the yield of flue-cured tobacco in an acid soil (pH 5.3), while lead to a decrease in potassium (K) concentration in cured leaves. Moreover, recently, Deng et al. (2019) found that lime application at a rate of 2.25 t ha$^{-1}$ significantly increased the soil pH from 5.05 to 5.38 but did not significantly enhanced the yield of flue-cured tobacco. Although the application of lime can increase the soil pH and alleviate soil acidification, different studies have found diverse conclusions on the effect of lime on the yield and quality of tobacco leaves. The differences in the effect of liming on tobacco are likely to be due to the different type and rate of lime materials, fertilizer application, tobacco varieties and cultivation environment (Karaivazoglou et al., 2007; Jiang et al., 2015a; Deng et al., 2019). Therefore, the suitable type and rate of lime application on tobacco acid soils is limited and needs to be further explored.

Tobacco is an important industrial crop in China, and plays an important economic role for both the national tax income (Zou et al., 2018). Especially, flue-cured tobacco is a main source of many farmers’ income, due to the good quality of tobacco leaves in Anhui province (Dong et al., 2015). Soil acidity has always been the main factor limiting tobacco leaves yield and quality, particularly in Anhui province due to the inherent low soil pH and excessive application of N fertilizer (Jiang et al., 2015a). Previous studies have shown that the soil pH for producing high quality tobacco is range from 5.5 to 6.5 (Shao et al., 2012; Jiang et al., 2015a). At present, liming is a common practice for ameliorating acid soils and improve crop yield, and is widely applied to the tobacco acid soils in southern China (Jiang et al., 2015a; Zou et al., 2018). However, research on the effect of liming on plant growth and leaves quality of flue-cured tobacco in the acidic soil is still limited. Therefore, in this study, a pot experiment was carried out to determine the effect of liming on soil nutrient status (Ca$^{2+}$ and Mg$^{2+}$ in particular), plant growth, nutrient (including micronutrients) accumulation and quality characteristics of tobacco leaves in an acidic soil in Anhui province, China.

Materials and methods

**Experiment site and growth conditions**

The pot experiment was carried out under greenhouse conditions in Chizhou, a major tobacco-producing area of Anhui province, China. The soil was collected from the tobacco field (0–20 cm), with a pH of 5.35, 18.2 g kg$^{-1}$ organic matter, 152.8 mg kg$^{-1}$ alkali-hydrolyzed N, 17.6 mg kg$^{-1}$ available phosphorus (P) and 168.3 mg kg$^{-1}$ available K. During the experiment, the tobacco plants were kept in a greenhouse with a (29±3)°C/(19±3)°C day/night temperatures, and a 70±10% relative humidity.
Experimental design and Management

Treatments consisted of four levels of lime (Ca(OH)_2), namely 0 (CK), 0.75 (Ca1), 1.5 (Ca2) and 3.0 t ha^{-1} Ca(OH)_2 (Ca3) in the experiment. In tobacco growing area of Chizhou, the tobacco plants were cultured in 1.2 m spaced rows with 0.5 m distance. Therefore, it should add 0, 6.67, 13.33, 26.67 g Ca(OH)_2 per pot cultivating one tobacco plant for the CK, Ca1, Ca2 and Ca3, respectively. The pot was 35 cm in diameter and 28 cm in height, containing 20 kg of air-dried and 2 mm-sieved soil. The Ca(OH)_2 (AR) powder and all the fertilizers needed for the flue-cured tobacco were applied as basal and fertilizer and mixed thoroughly with soil in the pot two days before the seedlings transplanting. Fertilizers were used as Jiang et al. (2015b).

Flue-cured tobacco (Nicotiana tabacum L., cv. Yunyan 87) seedlings were transplanted to individual pots when they were about 12 cm in height. The pots were placed neatly according to the plant spacing of 120 cm and the row spacing of 50 cm. Each treatment was replicated three times and each replicate included six plants (i.e. 18 plants per treatment). During the period of 60–65 days after transplanting, when approximately 50% of the plants in each plot were at full bloom, they were topped (Karaivazoglou et al., 2007). Tobacco leaves were harvested five times by hand starting 70–80 days after transplanting. Three or five leaves were removed by hand at 7- or 8-day intervals when the leaves were mature and turn yellow from bottom to top, and cured immediately in a flue-curing barn. Photos of the experimental culture were shown in Figure 1.

![Figure 1. Photos of the experimental culture before the seedlings transplanting (a) and 90 days after transplanting (b)](image)

Sample collection and determination

Plant height, leaf number and stem diameter were measured after topping of the tobacco plant. The plants were divided into leaves, stems and roots, and dry weights were measured after being dried to constant weight at 65 °C.

The cured leaves (from nodes 8 to 12) were used to determine appearance quality, smoking quality and the concentrations of elements. Both the appearance quality and the smoking quality of the leaves were graded using a scale from 1 to 10 (quality index) (Karaivazoglou et al., 2007). The appearance quality included maturity, structure, status, oil, color and chroma of the cured leaf. The smoking quality included aroma quality and quantity, fineness, roundness, hygroscopicity and uniformity of the cured leaf. For elements analysis, the leaves samples were dried to constant weight at 65 °C,
and milled into powder. The N concentration was analyzed according to the method of Karaivazoglou et al. (2007). The K, calcium (Ca) and magnesium (Mg) concentration were determined according to the method of Shao et al. (2012) and Tang et al. (2013).

Before the experiment, soils were collected to determine the basic fertility. At 30 days after transplanting, soils of each treatment were sampled for determining the soil pH. After harvest, soil samples were collected from each treatment for pH, exchangeable Ca and exchangeable Mg analysis. Soil pH, organic matter, alkali-hydrolyzed N, available P, available K, exchangeable Ca and exchangeable 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 SPSS 19.0 (SPSS Inc., Chicago, IL, USA). The treatments were compared by the method of least significance difference at \( P < 0.05 \).

Results

Effect of liming on plant height, leaf number, and dry weight of tobacco plant

As showed in Table 1, Ca application had a significant effect on plant height, leaf number, and dry weight of the tobacco plant. The plant height and leaf number of Ca2 were significantly increased by 9% and 15% compared with the CK, respectively, but no significant difference was found between the Ca2 and Ca3 treatments. However, the stem diameter of tobacco plant was not significantly affected by Ca application at the rate of 0.75 to 3.0 t ha\(^{-1}\) Ca(OH)\(_2\). The leaf and total dry weight of the tobacco plant was highest in Ca2 treatment, which was 11% and 17% higher than that of the CK, respectively. Similarly, Ca2 treatment achieved the highest root and leaf dry weight among all treatments. The root/shoot ratio of Ca2 treatment was significantly higher than that of the CK, Ca1 and Ca3 treatments.

Table 1. Effects of Ca(OH)\(_2\) application on plant height, leaf number, stem diameter and dry weight of tobacco plant

| Treatments | Plant height (cm) | Number of leaves per plant | Stem diameter (cm) | Dry weight (g plant\(^{-1}\)) | Root/shoot |
|------------|-------------------|-----------------------------|-------------------|-----------------------------|------------|
|            |                   |                             |                   | Root | Leaves | Total |                   |
| CK         | 88.0 b            | 20.3 b                      | 83.0 a            | 22.1 b | 72.0 b | 117.4 b | 0.23 b            |
| Ca1        | 90.3 b            | 21.0 b                      | 84.7 a            | 22.8 b | 73.9 b | 121.0 b | 0.23 b            |
| Ca2        | 95.7 a            | 23.3 a                      | 88.7 a            | 29.3 a | 79.6 a | 136.9 a | 0.27 a            |
| Ca3        | 92.0 ab           | 21.7 ab                     | 86.7 a            | 25.0 b | 75.6 ab | 126.7 ab | 0.25 b            |

Means within a column that have different letters are significantly different from each other at \( P < 0.05 \). The CK, Ca1, Ca2 and Ca3 are respectively 0, 0.75, 1.5 and 3.0 t ha\(^{-1}\) Ca(OH)\(_2\).

Effect of liming on concentrations of elements in tobacco leaf

As showed in Table 2, lime application significantly decreased the N concentration in tobacco leaves. However, liming did not significantly affect the K concentration in tobacco leaves. The Ca concentration in leaves of Ca1, Ca2 and Ca3 was significantly increased by 43%, 59% and 109% than that of the control without Ca, respectively. The
Ca concentration in leaves was significantly increased with an increased Ca application rate. However, the Mg concentration in leaves declined with an increase of the Ca application rate, and the Ca2 and Ca3 treatments resulted in 23% and 30% decrease of Mg concentration in leaves compared with the CK, respectively. Similarly, Ca application also decreased the P concentration in leaves. Under the Ca3 treatment, the P concentration in leaves was reduced by 15% than that of the CK.

Table 2. Effect of Ca(OH)$_2$ application on concentrations (g kg$^{-1}$ DW) of N, P, K, Ca and Mg in leaves of tobacco plant

| Treatments | N   | P   | K   | Ca  | Mg  |
|------------|-----|-----|-----|-----|-----|
| CK         | 30.9 a | 5.29 a | 19.8 a | 30.2 c | 4.18 a |
| Ca1        | 27.0 b | 4.75 ab | 21.4 a | 43.3 b | 4.05 a |
| Ca2        | 27.3 b | 4.91 ab | 21.2 a | 47.9 b | 3.23 b |
| Ca3        | 28.1 b | 4.48 b   | 20.3 a | 63.2 a | 2.92 b |

Means within a column that have different letters are significantly different from each other at $P < 0.05$. The CK, Ca1, Ca2 and Ca3 are respectively 0, 0.75, 1.5 and 3.0 t ha$^{-1}$ Ca(OH)$_2$.

The effect of Ca application on concentrations of microelements in tobacco leaf was showed in Table 3. The application of Ca resulted in a reduction of iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) in tobacco leaf. Compared with the CK, the Ca3 treatment significantly decreased Fe, Mn, Cu and Zn in tobacco leaf by 52%, 71%, 45% and 51%, respectively; and the Ca2 treatment significantly decreased Fe, Mn and Zn in tobacco leaf by 34%, 37% and 29%, respectively. In contrast, Ca application significantly increased the chloride (Cl) concentration in tobacco leaf compared with the CK, and the Cl concentration in leaves was increased with the increase of Ca application rate.

Table 3. Effect of Ca(OH)$_2$ application on concentration of micronutrients in leaves of tobacco plant

| Treatments | Fe (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) | Cl (g kg$^{-1}$) |
|------------|------------------|------------------|------------------|------------------|-----------------|
| CK         | 530.7 a          | 749.1 a          | 12.10 a          | 109.6 a          | 3.32 c          |
| Ca1        | 447.0 ab         | 659.7 a          | 10.84 a          | 98.2 ab          | 4.25 b          |
| Ca2        | 350.5 bc         | 473.3 b          | 9.70 ab          | 77.9 bc          | 4.67 ab         |
| Ca3        | 258.5 c          | 215.1 c          | 6.60 b           | 53.7 c           | 4.91 a          |

Means within a column that have different letters are significantly different from each other at $P < 0.05$. The CK, Ca1, Ca2 and Ca3 are respectively 0, 0.75, 1.5 and 3.0 t ha$^{-1}$ Ca(OH)$_2$.

Effect of liming on appearance and smoking quality of cured leaf

The application of Ca had a significant effect on the appearance and smoking quality of cured leaves (Fig. 2). Both the appearance and smoking quality of cured leaves were highest in Ca2, and increased by 7% and 9% compared with the control, respectively. However, there was no significant difference was observed between treatments Ca1 and Ca2 in the appearance and smoking quality of cured leaves. Moreover, Ca3 treatment...
did not significantly affect the smoking quality of cured leaves or even showed a
declining trend in appearance quality compared with the control.

![Figure 2](image_url)

**Figure 2.** Effect of Ca(OH)\(_2\) application on appearance and smoking quality of tobacco leaves. The CK, Ca1, Ca2 and Ca3 are respectively 0, 0.75, 1.5 and 3.0 t ha\(^{-1}\) Ca(OH)\(_2\). The error bars indicate standard error. Columns with different letters indicate significant difference among different treatments (P < 0.05)

**Effect of liming on soil pH and calcium and magnesium content**

As showed in **Figure 3**, Ca application significantly increased the soil pH 30 days after transplanting and after harvest. Compared with the CK, the soil pH was significantly increased by 0.30, 0.61 and 0.81 units in Ca1, Ca2 and Ca3 treatments 30 days after transplanting, respectively; and by 0.24, 0.36 and 0.73 units, respectively. After harvest, the highest soil pH was found in Ca3 treatment (6.02), which was significantly higher than the other treatments; however, there was no significant difference in soil pH between the CK and Ca1 treatments.

![Figure 3](image_url)

**Figure 3.** Effect of Ca(OH)\(_2\) application on soil pH. The CK, Ca1, Ca2 and Ca3 are respectively 0, 0.75, 1.5 and 3.0 t ha\(^{-1}\) Ca(OH)\(_2\). The error bars indicate standard error. Columns with different letters indicate significant difference among different treatments (P < 0.05)
Furthermore, the effect of liming on soil exchangeable Ca\(^{2+}\) and Mg\(^{2+}\) was investigated. The exchangeable Ca content of soil was increased with an increased Ca application rate (Fig. 4 and Fig. 5). Compared with the CK treatment, Ca2 and Ca3 significantly increased the exchangeable Ca content of soil by 16%, 100% and 147%, respectively. In contrast, the exchangeable Mg content of soil was decreased with the increase of Ca application rate. The Ca2 and Ca3 treatments resulted in 24% and 29% decrease in exchangeable Mg content of soil compared with the CK, respectively. However, there was no significant difference in both the exchangeable Ca and Mg content of soil between the CK and Ca1 treatment.

![Figure 4](image1.png)  
**Figure 4.** Effect of Ca(OH)\(_2\) application on exchangeable Ca and Mg content of soil. The CK, Ca1, Ca2 and Ca3 are respectively 0, 0.75, 1.5 and 3.0 t ha\(^{-1}\) Ca(OH)\(_2\). The error bars indicate standard error. Columns with different letters indicate significant difference among different treatments (P < 0.05)

![Figure 5](image2.png)  
**Figure 5.** Relationship between Ca(OH)\(_2\) application rate and soil exchangeable cations (Ca and Mg) content. Data were the means of three replicates.
Discussion

Liming is a common practice to alleviate soil acidification and improve crop yield in acidic soils (Crusciol et al., 2016; Holland et al., 2018; Liao et al., 2018). In this study, lime (Ca(OH)$_2$) application significantly enhanced leaves plant dry weight of flue-cured tobacco on an acidic soil, which is consistent with previous studies in Virginia tobacco (Karaivazoglou et al., 2007), rice (Jiang et al., 2018), and sugarcane (Pang et al., 2019). The improvement plant growth and dry weight in flue-cured tobacco were associated with the increase in plant height and higher leaf number per plant (Table 1), in agreement with the findings of Karaivazoglou et al. (2007) in flue-cured tobacco. Crop yield was increased by liming in acidic soils was mainly due to increase soil pH and improving the availability of soil nutrients (López-Lefebre et al., 2001; Zeng et al., 2017; Liu et al., 2018). In this study, soil pH was significantly increased by 0.36 units in the treatment received 1.5 t ha$^{-1}$ in comparison to without liming (pH 5.29) (Fig. 3), and the plant total dry weight was increased by 17% (Table 1). Although numerous studies have shown that liming significantly increased crop yield on acidic soils, continuous or excessive application of lime also lead to a significant decrease in crop yield (Zhang and Zheng, 1987; Zeng et al., 2017). The present results showed that the application of lime at a relatively high rate (3.0 t ha$^{-1}$) did not significantly affect the plant total dry weight, plant height and leaf number per plant (Table 1), in contrast to previous studies (Karaivazoglou et al., 2007). The optimal rate of lime to improve acidic soil and enhance crop yield was quite various in different studies may be due to rainfall and soil water content as these factors affect the rate and extent of lime dissolution and subsequent plant response (Liu et al., 2004; Hu et al., 2016; Zhang et al., 2019). We recognize that more field trials are needed to provide more evidences that liming can improve the growth and yield of flue-cured tobacco. The present study provides clear evidence that the optimal rate of liming was 1.5 t ha$^{-1}$ for flue-cured tobacco growth and development in an acidic soil with a pH below 5.5.

Furthermore, appropriate rate (1.5 t ha$^{-1}$) of lime application on acidic soil significantly improved the appearance and smoking quality of tobacco leaves (Fig. 2). The results are in agreement with Karaivazoglou et al. (2007), reported that liming significantly increased the quality index of cured leaves of Virginia tobacco. Also, many studies have shown that lime application increased the quality of tobacco cured leaves (Tang and Xiong, 2003; Zhu et al., 2016a,b; Deng et al., 2019). In relevant research, Zhu et al. (2016b) reported that tobacco plant growth and leaf quality were significantly improved at the lime application rate of 1.5 t ha$^{-1}$ for alleviating acidity of yellow soil (pH 5.0). Moreover, the physical and chemical properties and the smoking quality of tobacco leaves were increased by lime application rate of 2.25 t ha$^{-1}$ for the sustainable remediation of acid soil (Deng et al., 2019). One possible explanation for the improvement in smoking quality of tobacco leaves would be that liming of acid soils improved chemical composition availabilities of the cured leaves, particularly enhanced reducing sugar content in cured leaves (Zhu et al., 2016a; Deng et al., 2019). We also found that the reducing sugar content of cured leaves was increased at the lime application rate of 0.75 and 1.5 t ha$^{-1}$ (data not shown). However, there are still unclear how the lime application affected the sugar accumulation in tobacco leaves. Therefore, more attention should be paid on the relationship of Ca concentration and sugar content in tobacco cured leaves.

As expected, leaf Ca concentration increased significantly with increasing Ca(OH)$_2$ application rates in the soil. These results are in agreement with those reported by
Karaivazoglou et al. (2007), who reported that leaf Ca concentration was significantly increased by 10%, as Ca(OH)$_2$ application increased from 0 to 3 t ha$^{-1}$. López-Lefebre et al. (2001) also found that the Ca concentration in the leaves accumulated progressively with increasing CaCl$_2$ application in the culture medium. The increase in leaf Ca was mainly due to the increase in soil exchangeable Ca in the Ca(OH)$_2$ application treatments, because the Ca uptake in tobacco leaf was significant positive correlation with the content of soil available Ca (Zou and Xiong, 2010; Liu et al., 2017). However, excessive Ca concentration may result in a decline in the sensory quality of tobacco cured leaves (Duan et al., 2010; Dai et al., 2017). We found that the smoking quality of cured leaf of the Ca3 was significantly lower than that of the Ca1 and Ca2 (Fig. 2), which may probably due to the Ca3 greatly increased the Ca concentration of tobacco leaves (Table 2). Many studies have shown that Ca concentration of high quality tobacco leaves should be less than 35 g kg$^{-1}$ (Hu et al., 1997; Duan et al., 2010). Therefore, a suitable concentration of Ca in tobacco leaves must be considered for determining the optimal lime dosage for improving acidic soil.

In contrast, increasing the Ca(OH)$_2$ application rates diminished the leaf Mg concentration, the lowest concentration of Mg being found in Ca3 treatment, with a 30% decrease in comparison with the CK (Table 2). In agreement with our findings, López-Lefebre et al. (2001) reported that increasing CaCl application in the culture medium caused a gradual decline in Mg concentration in the roots and leaves. Duan et al. (2010) indicated that Mg concentration in leaf was increased by decreasing the soil Ca$^{2+}$/Mg$^{2+}$, i.e. an increase in soil exchangeable Ca will lead to the decrease of Mg concentration in tobacco leaves. In this study, the soil Ca$^{2+}$/Mg$^{2+}$ was significantly increased from on average 3.2 to 11.3 (Fig. 4), and the Mg concentration in leaf was decreased from 4.18 to 2.92 g kg$^{-1}$ (Table 2) by applying 3.0 t ha$^{-1}$ Ca(OH)$_2$ in acid soil. However, Karaivazoglou et al. (2007) found that Mg concentration of cured leaves was not significantly affected by Ca(OH)$_2$ application in acid soil. It was reported that the Mg concentration of superior tobacco leaves usually ranged from 4 to 15 g kg$^{-1}$, and low Mg concentration would reduce the quality of cured leaves (Xu et al., 2007; Duan et al., 2010). Therefore, the application of lime should increase the soil pH in acidic soil without reducing the Mg concentration to ensure the quality of tobacco leaves.

In addition, many studies have shown that K concentration is one of the most important indexes to evaluate the quality of tobacco leaves, and the K concentration of good quality tobacco leaves should be up to 25 g kg$^{-1}$ (Wei et al., 2011; Li et al., 2015; Yan et al., 2018). 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. In contrast, both Li et al. (2005) and Wei et al. (2011) found that calcium application improved the K uptake and increased the K concentration in flue-cured tobacco leaves. In this study, the leaf K concentration was numerically higher in the lime application treatments than in the control, but was not statistically significant (Table 2). The K concentration in tobacco leaves increased by lime application was probably due to Ca can have a direct, positive effect on K uptake, promoting the accumulation of K by the tobacco plant (Qiang et al., 2001; Wei et al., 2011). However, the positive effect of lime on K accumulation in tobacco leaves was not clearly reflected in the present study. Thus, further experiments, especially long-term field trials are needed to confirm whether and how the effect of liming on K accumulation in tobacco leaves.
Conclusion

The experiment explored the effect of liming on soil nutrient status, plant growth, nutrients accumulation and quality characteristics of flue-cured tobacco in an acid soil. The results confirmed that positive response of liming on ameliorating acidic soils, improving plant growth and yield. We found that liming enhances the growth and yield of flue-cured tobacco in an acid soil, and the appearance and smoking quality of cured leaves was improved with lime application at a rate of 1.5 t Ca(OH)$_2$ ha$^{-1}$. Furthermore, the soil pH was significantly increased from 5.29 to 5.65 in the treatment received 1.5 t Ca(OH)$_2$ ha$^{-1}$. Although long-term field experiments are needed to investigate the influence of liming on K concentration and quality in tobacco cured leaves, our results suggest that application of Ca(OH)$_2$ at a rate of 1.5 t ha$^{-1}$ may alleviate soil acidity, improve yield and quality of flue-cured tobacco, especially in soil with a pH below 5.5.

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