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Research Article

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The effects of soil pH on tobacco growth

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ABSTRACT

A pot experiment was carried out to study the effects of different soil pH values (7.0-9.0) on the nutrient absorption, agronomic traits, and chemical component levels of tobacco leaves. The results showed the following information. (1) The pH of the tobacco field soil affected its fertility. Increasing pH values caused small increases in the level of alkaline hydrolyzable N (Ah-N) and significant increases in the amount of available P (AP), available K (AK), available Fe (AFe), available Zn (AZn), and available Mn (AMn) in the soil. Higher soil pH also caused small increases in the levels of N and P, small decreases in the levels of Ca, Mg, Zn and significant decreases in the levels of Fe and Mn in the tobacco leaves. (2) Soil pH values affected the growth of the tobacco plants in the soil; excessively high pH values significantly decreased the single-leaf dry weight. (3) Soil pH also affected the quality of the tobacco leaves. The Cl^-, nicotine, and the difference between the amount of total sugar and that of reducing sugar (DBTR) levels all increased with increasing pH values. When the soil pH reached 8.6, the Cl^- content exceeded the optimum range (0.3%-0.8%). When the soil pH reached 9.0, DBTR level exceeded 5%.

Keywords: soil, pH value, tobacco, nutrient, tobacco leaf quality

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INTRODUCTION

Soil pH is an important factor that affects the growth of tobacco plants as well as the quality and yield of their tobacco leaves [1, 2]. It determines both the distribution of soil microbes and the nutrient absorption of tobacco [3-6]. The soil pH for achieving higher quality tobacco is different under different soil and climatic conditions. For example, the best pH for tobacco growth in the United States is 6.0-6.4, while in India, the best pH is 7.5 - 8.5, and in China, the soil pH found in high quality tobacco-growing areas is primarily in the range of 5.0 - 7.0[5]. Currently, the academic community considers the optimal pH for quality tobacco leaf production to be in the range of 5.5 - 6.5 [7-9]. Hunan is one of China's best tobacco-growing areas, and a survey by Chen [10] found that its soil pH ranges from 4.7 to 8.2; in that study, 25.8% of the tobacco-growing areas had pH values in the optimum range of 5.5 - 6.5, and 49.8% had pH values above 6.5. Xu et al. [9] found in another sampling survey that the order of soil pH (from high to low) in the different tobacco-growing areas of Hunan was as follows: Southern Hunan > Northern Hunan > Western Hunan > Eastern Hunan. A different study by Chen et al. [11] found that the soil pH in the tobacco-growing areas of southern Hunan, particularly in Chenzhou, were slightly acidic in the mid-1980s but have since shifted to be slightly alkaline. The effects of pH changes in the soils of southern Hunan on tobacco production have rarely been reported. In this study, soil samples were collected from tobacco-growing areas in Hunan, adjusted to different pH values (7.0-9.0), and used for tobacco pot experiments. The availability of soil nutrients and the levels of the nutrient elements, starch, Cl^-, nicotine, and disaccharides in the tobacco leaves were analyzed to investigate the effects of soil pH on the growth and quality of tobacco, providing a scientific explanation for the quality tobacco produced in the tobacco-growing areas of southern Hunan.

EXPERIMENTAL SECTION

2.1 Experimental materials

The soils for the pot experiments were collected from Wutong Village (Renyi, Guiyang County, Chenzhou City, Hunan Province). The soils were dried, and all debris and stones were removed from them. The physical and chemical properties of the test soils are shown in Table 1. The agents used to adjust the soil pH values were H_2SO_4 and NaOH, both of which were analytical grade. The fertilizer was used specially for tobacco (provided by Chenzhou Company of Hunan Tobacco Company).

Table 1 The physical and chemical properties of the tested soils

Soil pH value	Organic matter/ (%)	Total N/ ($g•kg^{-1}$)	Total P/ ($g•kg^{-1}$)	Total K/ ($g•kg^{-1}$)	Alkaline hydrolysable N/ ($mg•kg^{-1}$)	Available P/ ($mg•kg^{-1}$)	Available K/ ($mg•kg^{-1}$)
7.85	2.09	1.32	0.69	13.8	110.5	80.56	108.6

2.2 Pot experiments

After being dried, the soils were placed into a series of pots (15.0 kg of soil per pot). Five grams of specialized fertilizer was applied to each pot and mixed well. Then, the soil pH was adjusted to one of 6 levels using a solution of either H_2SO_4 or NaOH: 7.0, 7.4, 7.8, 8.2, 8.6, or 9.0. The first three pH levels were attained via the repeat addition of H_2SO_4 solution, while the latter three levels were reached using NaOH solution. After each addition of the acid or alkaline solution, the soil was balanced for 12 h, and the pH value was determined. Then, the acid or alkali solution was added again; the process was repeated multiple times to gradually approach the targeted soil pH. After the soils were balanced for 2 final weeks, tobacco plants of similar growth were planted in the pots; one plant was transplanted into per pot, and 3 replicates of each condition were made. The plants were grouped and arranged randomly in a greenhouse for cultivation. After harvesting, the tobacco leaves were hung to cure. The single-leaf dry weight was calculated, and the N, P, K, Ca, Mg, Cu, Zn, Mn, starch, Cl^-, nicotine, and the difference between the amount of total sugar and that of reducing sugar (DBTR) levels in the tobacco plants were determined. Additionally, soil samples were collected, air dried, ground, and passed through 2-mm and 0.149-mm nylon sieves. The pH value, organic matter (OM) content, and levels of alkaline hydrolyzable N (Ah-N), available P (AP), available K (AK), exchangeable Ca (ECa), exchangeable Mg (EMg), available Zn (AZn), available Cu (ACu), available Fe (AFe), and available Mn (AMn) in the soil samples were then determined.

2.3 Method of sample analysis

Soil pH was determined using a pH meter (PHS-3C, Leici) with a solid-liquid ratio of 1:2.5. The OM content was determined using the potassium dichromate colorimetric method, and soil Ah-N levels were determined by the alkaline hydrolysis diffusion method. The soil AP was determined by the Olsen method; the soil AK, ECa, and EMg were extracted using CH_3COONH_4; and the soil AFe, ACu, AZn, and AMn were extracted via DTPA solvent extraction and determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) (ICP 6300, Thermo) [12]. The N, P, and K in the tobacco leaves were digested using H_2SO_4-H_2O_2, and their levels were determined using distillation, the Mo-Sb colorimetric method, and ICP-AES, respectively. The Ca, Mg, Fe, Cu, Zn, and Mn in the tobacco leaves were digested using HNO_3-$HClO_4$ and determined by ICP-AES [12]. The starch, Cl^-, nicotine, and DBTR levels were determined with a continuous flow analyzer (SKALAR San++).

2.4 Method of data statistical analysis

The test data are shown as the mean ± standard deviation. All data were statistically analyzed using the significant F test and Duncan's multiple comparison method ($p < 0.05$) and processed with Excel 2010 and SPSS 19.0.

RESULTS AND DISCUSSION

3.1 Effects of soil pH on the availabilities of soil nutrients

3.1.1 Effects of soil pH on the availabilities of soil organic matter, N, P, K, Ca, and Mg

Table 2 shows that the soil pH had little effect on soil OM or ECa; however, as the pH value increased, the soil Ah-N increased slightly, AP and AK gradually decreased, and EMg slightly decreased. Compared with soil at pH 7.0, the soils with a more basic pH showed Ah-N increases of 3.97% - 10.26%, while the soil AP, AK, and EMg levels decreased by 16.56% - 36.27%, 4.30% - 21.13%, and 3.17% - 6.35%, respectively. Statistical analyses showed a highly significant positive linear correlation between the soil Ah-N level and its pH value ($R_{Ah\text{-}N} = 0.962$; n = 6, $R_{0.01} = 0.917$); as the soil pH increased, the Ah-N differences reached a significant level. At higher pH, changes in AP and AK reached significant levels, and there were highly significant negative linear correlations between AP and AK and the pH value ($R_{available\ P} = -0.894$, $R_{available\ K} = -0.971$; n = 6, $R_{0.05} = 0.811$, $R_{0.01} = 0.917$). No significant change was found in the EMg content. Overall, the soil Ah-N level increased, while the AK and AP levels significantly decreased, with increasing pH values.

Table 2 The effects of the soil pH value on the soil levels of organic matter (OM), alkaline hydrolysable N (Ah-N), available P (AP), available K (AK), exchangeable Ca (ECa), and exchangeable Mg (EMg)

Soil pH value	OM/ (%)	Ah-N/ (mg•kg^{-1})	AP/ (mg•kg^{-1})	AK/ (mg•kg^{-1})	ECa/ (cmol1/2Ca^{2+}•kg^{-1})	EMg/ (cmol1/2Mg^{2+}•kg^{-1})
7.0	(2.27±0.09)a	(108.2±3.9)c	(104.5±6.2)a	(151.0±12.3)a	(110.8±9.3)a	(1.89±0.04)a
7.4	(2.29±0.07)a	(112.5±5.2)abc	(87.2±12.4)ab	(144.5±6.5)a	(104.2±6.1)a	(1.83±0.13)a
7.8	(2.32±0.29)a	(111.2±3.8)bc	(79.8±10.8)ab	(145.1±7.1)a	(111.9±7.1)a	(1.77±0.11)a
8.2	(2.26±0.08)a	(115.4±2.3)ab	(70.6±21.9)b	(136.0±8.2)ab	(108.9±2.5)a	(1.78±0.04)a
8.6	(2.32±0.09)a	(117.0±4.1)ab	(77.9±14.4)b	(125.3±14.3)b	(106.7±6.9)a	(1.73±0.02)a
9.0	(2.30±0.11)a	(119.3±1.6)a	(66.6±11.0)b	(119.1±5.4)b	(112.1±2.2)a	(1.77±0.09)a

Note: The data are the average values ± SD (n=3). The data in the columns are significantly different when marked with different letters (p < 0.05), as is the case throughout the manuscript.

3.1.2 Effects of soil pH on the availabilities of soil Fe, Cu, Zn, and Mn

Table 3 shows that with increasing soil pH values, the soil levels of AFe, AZn, and AMn gradually decreased, while the ACu level only slightly decreased. Compared with soil at pH 7.0, soils with increasing pH values had AFe, ACu, AZn, and AMn decreases of 2.11% - 9.86%, 2.83% - 4.6%, 1.81% - 9.23%, and 3.07% - 18.03%, respectively. Statistical analyses indicated that increasing soil pH caused significant changes in the AFe, AZn, and AMn levels of soil but did not significantly alter ACu. There was a highly significant linear correlation between the soil pH and the soil levels of AFe, AZn, and AMn (R_{AFe} = 0.998, R_{AZn} = 0.944, R_{AMn} = 0.964; n = 6, $R_{0.01}$ = 0.917). Additionally, a significant negative linear correlation was found between the soil's ACu level and pH value (R_{ACu} = 0.878; n = 6, $R_{0.05}$ = 0.811). The soil levels of AFe, AZn, and AMn significantly decreased with increasing soil pH values, consistent with the results of Hao et al. [13], Straczek et al.[14] and Beverley et al. [15]. This correlation likely occurs because increasing pH values raise the level of soil OH^-, which forms hydroxides with Fe, Zn, and Mn that then precipitate, reduce the available amount of these metals.

Table 3 The effects of the soil pH value on the soil levels of available Fe (AFe), available Cu (ACu), available Zn (AZn), and available Mn (AMn)

Soil pH value	AFe/(mg•kg^{-1})	ACu/(mg•kg^{-1})	AZn/(mg•kg^{-1})	AMn/(mg•kg^{-1})
7.0	(14.2±0.1)a	(5.65±0.28)a	(9.97±0.03)a	(159.4±7.6)a
7.4	(13.9±0.6)ab	(5.49±0.12)a	(9.79±0.22)ab	(154.5±8.1)ab
7.8	(13.6±0.3)abc	(5.47±0.19)a	(9.87±0.14)ab	(150.1±15.8)ab
8.2	(13.4±0.4)abc	(5.50±0.32)a	(9.62±0.43)ab	(149.1±10.7)ab
8.6	(13.1±0.4)bc	(5.40±0.11)a	(9.34±0.36)bc	(141.1±16.5)ab
9.0	(12.8±0.5)c	(5.39±0.16)a	(9.05±0.39)c	(130.5±13.9)b

3.2 Effects of soil pH on the soil nutrient absorption of tobacco

3.2.1 Effects of soil pH on the levels of N, P, K, Ca, and Mg in tobacco leaves

Table 4 shows that as the soil pH value increased, the N and P levels in tobacco leaves slightly increased, while the K level did not show a significant change. A slight overall decrease in the Ca and Mg levels was also seen. Compared with soil at pH 7.0, increasing pH values increased the tobacco leaf levels of N, P by 2.46%-11.47% and 5.88%-11.76%, respectively. Additionally, the levels of Ca and Mg decreased by 2.8%-18.82%, 8.11%-19.63%, respectively. Statistical analyses showed that there was no significant variation in the K levels of tobacco leaves. However, significant differences were found in the N, P, Ca, and Mg levels; there was a significant positive linear correlation between the tobacco leaf's N level and the soil pH (R_N = 0.972; n = 6, $R_{0.01}$ = 0.91), as well as a significant negative linear correlation between the tobacco leaf's Mg level and the soil pH (R_{Mg} = -0.906; n = 6, $R_{0.05}$ = 0.811). The P and Ca in the tobacco leaves were not significantly affected by the soil pH value.

Table 4 The effects of the soil pH value on the levels of N, P, K, Ca, and Mg in tobacco leaves

Soil pH value	N/(%)	P/(%)	K/(%)	Ca/(mg•kg^{-1})	Mg/(mg•kg^{-1})
7.0	(2.84±0.24)b	(0.172±0.012)ab	(4.64±0.08)a	(23.06±2.01)a	(3.63±0.12)a
7.4	(2.82±0.17)b	(0.164±0.011)b	(4.67±0.15)a	(24.21±2.56)a	(3.33±0.25)ab
7.8	(2.91±0.14)ab	(0.183±0.008)ab	(4.67±0.23)a	(23.92±0.84)a	(3.20±0.16)bc
8.2	(3.00±0.14)ab	(0.174±0.012)ab	(4.64±0.11)a	(22.41±1.49)a	(3.25±0.05)bc
8.6	(3.10±0.07)ab	(0.178±0.007)ab	(4.72±0.11)a	(23.73±0.75)a	(3.20±0.24)bc
9.0	(3.16±0.17)a	(0.189±0.006)a	(4.68±0.05)a	(18.72±1.81)b	(2.92±0.23)c

3.2.2 Effects of soil pH on the levels of Fe, Cu, Zn, and Mn in tobacco leaves

Table 5 shows that the levels of Fe, Zn, and Mn in tobacco leaves decreased gradually with increasing soil pH, but the Cu content did not change significantly. Compared with tobacco plants grown in pH 7.0 soil, tobacco in higher pH values saw decreased leaf levels of Fe, Zn, and Mn by 14.12%-26.27%, 0.6%-9.6%, and 24.02%-43.59%, respectively. Statistical analyses showed that the Cu level in the tobacco leaves did not vary significantly, but the Fe, Zn, and Mn levels did; there was a very significant negative linear correlation between the tobacco leaf Fe levels and the soil pH (R_{Fe} = - 0.933; n = 6, $R_{0.01}$ = 0.91), and there were also significant negative linear correlations between the tobacco leaf Zn and Mn levels and the soil pH (R_{Zn} = 0.871, R_{Mn} = 0.836; n = 6, $R_{0.05}$ = 0.811). Overall, the Fe and Mn levels in the tobacco leaves decreased significantly and the Zn content decreased slightly in response to increasing soil pH, consistent with the decreased soil levels of AFe, AZn, and AMn shown in Table 3.

Table 5 The effects of soil pH on the levels of Fe, Cu, Zn, and Mn in tobacco leaves

Soil pH value	Fe/(mg•kg^{-1})	Cu/(mg•kg^{-1})	Zn/(mg•kg^{-1})	Mn/(mg•kg^{-1})
7.0	(80.7±13.4)a	(39.8±2.1)a	(33.3.±1.1)a	(56.2±12.1)a
7.4	(69.3±8.1)ab	(39.7±0.8)a	(33.1±0.7)a	(42.7±9.7)b
7.8	(69.7±12.7)ab	(38.8±1.9)a	(32.4±0.5)a	(40.7±2.2)b
8.2	(65.0±5.3)ab	(40.2±1.0)a	(32.9±1.3)a	(39.4±2.1)b
8.6	(64.1±8.7)ab	(40.7±0.7)a	(31.8±1.5)ab	(37.1±0.9)b
9.0	(59.5±9.0)b	(39.2±1.1)a	(30.1±0.8)b	(31.7±2.0)b

3.3 Effects of soil pH on the agronomic traits of tobacco plants

Table 6 shows that increasing soil pH values led to decreases in tobacco plant height and single-leaf weight, while the effective number of leaves per plant did not change significantly. Compared with soil at pH 7.0, more basic soils caused the tobacco plant height and single-leaf weight to decrease by 3.63%-9.95% and 0.3%-21.29%, respectively. Statistical analyses showed no significant difference in plant height or effective number of tobacco leaves between treatments with different pH values, but the single-leaf weight differed significantly. In other words, the plant height and effective number of leaves were not linearly correlated with the soil pH, but there was a significant negative linear correlation between the tobacco single-leaf weight and the soil pH value ($R_{single\text{-}leaf\ weight}$ = -0.879; n = 6, $R_{0.05}$ = 0.811). Excessively high soil pH had a negative impact on the growth of tobacco plants.

Table 6 The effects of the soil pH value on the agronomic traits of tobacco

Soil pH value	Plant height/(cm)	Effective number of leaves/plant	Single-leaf weight/(g)
7.0	(63.3±3.2)a	(19.7±1.2)a	(6.67±0.50)a
7.4	(61.0±3.6)a	(19.0±1.7)a	(6.65±1.24)a
7.8	(62.0±4.6)a	(20.3±3.8)a	(6.19±0.58)ab
8.2	(63.3±3.1)a	(19.3±0.6)a	(6.52±0.24)a
8.6	(57.7±4.7)a	(20.3±1.5)a	(5.86±0.20)ab
9.0	(57.0±3.0)a	(19.7±2.1)a	(5.25±0.33)b

3.4 Effects of soil pH on the levels of starch, Cl^-, nicotine, and DBTR in tobacco leaves

Table 7 lists the analysis results for several chemical components in the tobacco leaf samples, including starch, Cl^-, nicotine, and disaccharides. The starch, Cl^-, nicotine, and DBTR levels in tobacco leaves all increased with increasing soil pH. Compared with soil at pH 7.0, higher pH soils caused the levels of starch, Cl^-, nicotine, and disaccharides in the tobacco leaves to increase by 0.78%-9.41%, 4.17%-41.67%, 3.72%-25.62%, and 5.61%-26.83%, respectively. Statistical analyses showed no significant difference in starch levels but a significant difference in the levels of Cl^-, nicotine, and DBTR. The nicotine and DBTR levels were both significantly positively and linearly correlated with soil pH ($R_{nicotine}$ = 0.969, R_{DBTR} = 0.977; n = 6, $R_{0.01}$ = 0.91), whereas there was no significant correlation between Cl^- and soil pH (R_{Cl^-} = 0.808; n = 6, $R_{0.05}$ = 0.811). Starch is a type of polysaccharide that is easily hydrolyzed. After curing, the starch level remaining in tobacco leaves was low. The presence of sugars in the form of starch had an adverse effect on the quality of cigarette smoke for the user because it affected the rate and completeness of burning; in addition, it produced a burning smell, harming the aroma of the tobacco [16, 17]. Cl^- is closely related to the combustibility, moisture absorption, and flexibility of tobacco leaves. Excessively high or excessively low Cl^- content affects the quality of the tobacco leaves, and the optimum Cl^- level of flue-cured tobacco should be 0.3%-0.8% [11,18]. Nicotine is another important factor affecting the quality of tobacco leaves [19]. Some scholars examining the nicotine content of Hunan's flue-cured tobacco found that the aroma and smoke flavor were best when the nicotine content fell between 2.5 and 3.5% [20, 21]. The total amounts of water-soluble and reducing sugars are the primary factors determining smoking quality [22]. Additionally, DBTR is an important indicator of the intrinsic chemical quality of flue-cured tobacco. If DBTR is above 5%, the quality of the taste deteriorates [23]. Under the experimental conditions of our study, the Cl^- content exceeded the optimum range of 0.3%-0.8% when the soil pH reached 8.6, and DBTR exceeded 5% when the soil pH reached 9.0. The soil pH value had a significant impact on the Cl^-, nicotine, and DBTR levels; excessively high soil pH values decreased the quality of tobacco leaves.

Table 7 The effects of the soil pH value on the levels of starch, Cl^-, nicotine, and DBTR in tobacco leaves

Soil pH value	Starch/(%)	Cl^-/(%)	Nicotine/(%)	DBTR/(%)
7.0	(5.10±0.13)a	(0.72±0.04)b	(2.42±0.09)d	(4.10±0.32)c
7.4	(5.02±0.26)a	(0.75±0.09)b	(2.51±0.08)cd	(4.08±0.12)c
7.8	(5.14±0.06)a	(0.77±0.03)b	(2.75±0.15)b	(4.33±0.17)c
8.2	(5.13±0.05)a	(0.71±0.13)b	(2.70±0.13)bc	(4.71±0.10)b
8.6	(5.25±0.15)a	(0.87±0.07)ab	(2.88±0.11)ab	(4.97±0.10)ab
9.0	(5.18±0.32)a	(1.02±0.12)a	(3.04±0.18)a	(5.20±0.28)a

CONCLUSION

(1) The pH of a tobacco field's soil affects its fertility. The soil pH value had various effects on the Ah-N, AP, AK, AFe, AZn, and AMn levels in the soil. Compared with soil at pH 7.0, more basic soil had Ah-N increases of 3.97%-10.26%, while its levels of AN, AP, AK, AFe, AZn, and AMn decreased by 16.56%-36.27%, 4.30%-21.13%, 2.11%-9.86%, 1.81%-9.23%, and 3.07%-18.03%, respectively. The soil pH value also affected the levels of N, P, Ca, Mg, Fe, Zn, and Mn in the tobacco leaves of plants grown in the soil. Compared with soil at pH 7.0, higher soil pH values increased the N and P levels in tobacco leaves by 2.46%-11.47% and 5.88%-11.76%, respectively, while decreasing their Ca, Mg, Fe, Zn, and Mn levels by 2.82%-18.82%, 8.11%-19.63%, 14.12%-26.27%, 0.6%-9.6% and 24.02%-43.59%, respectively.

(2) Increasing the soil pH inhibited the growth of tobacco plants, and excessively high pH values significantly decreased the single-leaf weight of the tobacco. Compared with soil at pH 7.0, higher soil pH values decreased the single-leaf weight by 0.3%-21.29%.

(3) Excessively high soil pH decreased the quality of the tobacco leaves grown in the soil. The Cl^-, nicotine, and DBTR levels gradually increased with increasing pH values. The Cl^- levels exceeded the optimum range of 0.3%-0.8% when the soil pH reached 8.6, and DBTR exceeded 5% when the soil pH reached 9.0.

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