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A Brief Study on pH, Exchangeable Ca^{2+} and Mg^{2+} in Farmlands under Tobacco-Rice Rotation in Xuancheng City of South Anhui

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Abstract

pH, exchangeable Ca^{2+} and Mg^{2+} of soil can influence the yield and quality of flue-cured tobacco. Xuancheng city is the dominant tobacco-planting region in Anhui province since 2008. A general soil survey was conducted in Xuancheng city to understand the current situations of pH, exchangeable Ca^{2+} and Mg^{2+} of farmlands under tobacco-rice rotation and to decide whether continuous applying dolomite powders to abate soil acidification. In total 124 topsoil samples (0 - 20 cm) were collected from the typical farmlands and soil pH, exchangeable Ca^{2+} and Mg^{2+} were measured. The results showed that soil pH and Ca^{2+} and Mg^{2+} in Xuancheng city were generally in the suitable grades, pH ranged from 4.56 to 8.42 with an average of 5.87, exchangeable Ca^{2+} ranged from 1.01 cmol(1/2Ca^{2+}) kg^{-1} to 100.55 cmol(1/2Ca^{2+}) kg^{-1} with an average of 11.07 cmol(1/2Ca^{2+}) kg^{-1}, and exchangeable Mg^{2+} ranged from 0.14 cmol(1/2Mg^{2+}) kg^{-1} to 2.86 cmol(1/2Mg^{2+}) kg^{-1} with an average of 0.81 cmol(1/2Mg^{2+}) kg^{-1}, all spanned from the low grades to the high grades. To the whole Xuancheng city, 37.10%, 62.10% and 72.58% of the surveyed farmlands were in the low grades of pH, exchangeable Ca^{2+} and Mg^{2+}, respectively, while 52.42%, 25.00% and 20.97% of the farmlands were in the suitable grades, respectively. pH had an extremely significantly positive Napierian logarithm correlation with exchangeable Ca^{2+} and an extremely significantly positive power correlation with exchangeable Mg^{2+}. In total about 338.2 $kg{\cdot}hm^{-2}$ of Ca^{2+} and 202.4 $kg{\cdot}hm^{-2}$ of Mg^{2+} are annually input into the farmlands, while about 110.4 $kg{\cdot}hm^{-2}$ of Ca^{2+} and 7.4 $kg{\cdot}hm^{-2}$ of Mg^{2+} are annually moved out from the farmlands, exchangeable Ca^{2+} and Mg^{2+} were annually increased by 225.2 $kg{\cdot}hm^{-2}$ and 187.6 $kg{\cdot}hm^{-2}$ in the farmlands, respectively. It

is necessary to monitor the farmlands dynamically in order to decide whether continuous applying dolomite powders which should be dependent upon the specific conditions of individual farmlands.

Keywords

pH, Exchangeable Ca^{2+} and Mg^{2+}, Dolomite Powders, Farmlands, Tobacco-Rice Rotation, Xuancheng City

1. Introduction

pH, exchangeable Ca^{2+} (exc. Ca^{2+}) and Mg^{2+} (exc. Mg^{2+}) of soil can influence the yield and quality of flue-cured tobacco [1] [2] [3]. For tobacco planting, the reasonable soil pH is ranged from 5.5 to 7.0, while the suitable exc. Ca^{2+} and Mg^{2+} are from 6 to 10 cmol(1/2Ca^{2+}) kg^{-1} and 1.0 to 1.6 cmol(1/2Mg^{2+}) kg^{-1}, respectively [4] [5]. However, most of the tobacco planting farmlands in south China are acid and insufficient in exc. Ca^{2+} and Mg^{2+} [6] [7], so it is common to apply dolomite powders (C_2CaMgO_6), quicklime (CaO) or calcium magnesium phosphate fertilizer to adjust soil pH and supply Ca and Mg nutrients [7] [8] [9] [10].

Xuancheng city is the dominant tobacco planting region in Anhui province since 2008 with a regular tobacco-planting area of about 1×10^4 hm^2 (constituted by 90% more of the tobacco-planting area in Anhui province) and a yield of tobacco leaves of about 1×10^4 t [11]. Similarly, the tobacco-planting farmlands in Xuancheng city also face the same problems of acidification and insufficient exc. Ca^{2+} and Mg^{2+} [12] [13], for example, the area percentage of the farmlands with pH < 5.5 was increased from 30% of total farmland in 1980's (data of the 2nd National Soil Survey) to 60% of the total farmland in 2007 (data of the Soil Testing and Formulated Fertilization Project). Thus, dolomite powders which are alkaline and rich in Ca and Mg have been widely even intensively in the recent decade [7] [8] [9].

Currently, the local farmers urgently want to know the present situations of soil pH and exc. Ca^{2+} and Mg^{2+} in the farmlands in order to decide whether continues applying dolomite powders. Thus, in December 2015 a general soil survey was conducted in Xuancheng city in which topsoil samples (0 - 20 cm) were collected from the typical farmlands under tobacco-rice rotation and soil pH, exc. Ca^{2+} and Mg^{2+} were measured.

2. Methods and Materials

2.1. General Situation of Xuancheng City

Xuancheng city is located in the south Anhui province (117˚58'E - 119˚40', 29˚57' - 31˚19'N) with a total area of 1.23×10^4 km^2, the mean annual sunshine duration, temperature, precipitation, dryness and frost-free period is 1784 h, 15.6˚C, 1200 - 1500 mm, 0.68 - 0.90 and 240 d, respectively, the landform is

complex and diverse, mountains, hills and valley basins are interlaced in the south with a mean altitude of 1200 - 1800 m, hills and downlands are distributed in the middle with a mean altitude of 15 - 100 m, while alluvial plains are dominant in the north with a mean altitude of 7 - 12 m. The tobacco-planting soils are mainly paddy soils mainly under tobacco-rice rotation. The annual fertilization is pure N 90 - 120 kg·hm^{-2} with N:P_2O_5:K_2O of 1:1.4 - 1.7:3.2 - 3.5 in the tobacco planting season while pure N 180 - 225 kg·hm^{-2} with N:P_2O_5:K_2O of 1:0.5:0.8 in the rice planting season. For acid farmland (topsoil pH < 5.5), about 1500 kg·hm^{-2} of 250 μm-diameter dolomite powders are applied before planting tobacco, which is proved to increase soil pH by one unit [8].

2.1. Soil Sampling and Measurement

Based on the database of tobacco farmers of Wannan Tobacco Ltd. Company in 2015, in total 124 typical tobacco-planting farmlands were determined according to their spatial distributions (see **Figure 1** and **Table 1**), these farmlands belonged to different model tobacco farmers due to their excellent skills in flue-cured tobacco planting and great planting area (about 2 - 7 hm^2) of tobacco.

Random multipoint method was used for the topsoil sampling (0 - 20 cm) in each typical farmland. Soil samples were air dried, ground and passed 1 mm and 0.25 mm sieves, then pH was determined by potentiometer, exc. Ca^{2+} and Mg^{2+} were by atomic absorption spectrophotometer after extracted by ammonium acetate [14] [15] [16].

2.2. Classification of Soil pH and Exc. Ca^{2+} and Mg^{2+}

Table 2 is the grading standards of soil pH and exc. Ca^{2+} and Mg^{2+} for tobacco planting [4] [5].

2.3. Data Processing and Thematic Mapping

Data were analyzed with Microsoft Excel 2013 and IBM Statistics SPSS 20.0, the spatial distribution of topsoil samples was mapped on the platform of Esri Arc-GIS 10.3.

3. Results and Discussions

3.1. General Statistics of Soil pH and Exc. Ca^{2+} and Mg^{2+}

Table 3 shows the statistic information of topsoil pH and exc. Ca^{2+} and Mg^{2+} of typical tobacco planting farmlands in Xuancheng.

For soil pH, it ranged from the low grade to the high grade in the whole Xuancheng city, also ranged from the low grade to the high grade in Xuanzhou district, Langxi county and Jing county, meanwhile ranged from the low grade to the suitable grade in Jingde county, Guangde county and Ningguo city.

For soil exc. Ca^{2+}, it ranged from the low grade to the high grade in the whole Xuancheng city, also ranged from the low grade to the high grade in Xuanzhou

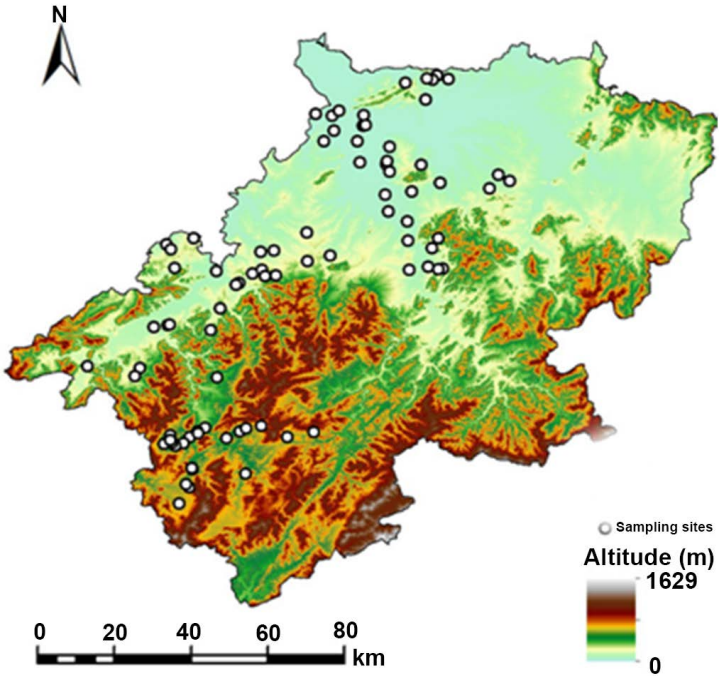

Figure 1. Spatial distribution of sampling sites of farmlands under tobacco-rice rotation in Xuancheng.

Table 1. Regional distribution of surveyed farmlands under tobacco-rice rotation in Xuancheng.

Region	Xuanzhou district	Langxi county	Jingde county	Jing county	Guangde county	Ningguo city	Total
Sample No.	42	11	21	29	13	8	124

Table 2. Classification of soil pH and exchangeable Ca^{2+} and Mg^{2+} for tobacco planting.

Soil indicator	Low	Suitable	High
pH	<5.5	5.5 - 7.0	>7.0
Exc. Ca^{2+} [cmol(1/2Ca^{2+}) kg^{-1}]	<6	6 - 10	>10
Exc. Mg^{2+} [cmol(1/2Mg^{2+} kg^{-1}]	<1.0	1.0 - 1.6	>1.6

district, Langxi county, Jingde county, Jing county and Guangde county, meanwhile from the low grade to the suitable grade in Ningguo city.

For soil exc. Mg^{2+}, it ranged from the low grade to the high grade in the whole Xuancheng city, also ranged from the low grade to the high grade in Xuanzhou district, Langxi county, Jingde county, Jing county and Guangde county, meanwhile only concentrated in the low grade in Ningguo city.

3.2. Statistics of Grade Proportions of Soil pH and Exc. Ca^{2+} and Mg^{2+}

Table 4 shows the sample number distribution in various grades of soil pH and exc. Ca^{2+} and Mg^{2+}.

Table 3. Statistics of topsoil pH and exc. Ca^{2+} and Mg^{2+} of farmlands under tobacco-rice rotation in Xuancheng.

Indicators		Xuanzhou	Langxi	Jingde	Jing	Guangde	Ningguo	Total
pH	Range	4.56 - 8.42	4.69 - 8.14	4.81 - 6.20	4.96 - 8.32	4.83 - 6.86	4.58 - 6.66	4.56 - 8.42
	Mean/S.D.	5.99/0.95	5.59/0.88	5.58/0.34	6.25/1.00	5.61/0.59	5.51/0.68	5.87/0.87
Exc. Ca^{2+} cmol(1/2Ca^{2+}) kg^{-1}	Range	1.06 - 95.06	2.29 - 19.01	2.77 - 10.50	1.34 - 100.55	1.01 - 13.85	1.64 - 8.91	1.01 - 100.55
	Mean/S.D.	11.43/19.08	5.16/4.51	6.13/2.22	20.56/31.78	4.77/3.48	4.80/2.31	11.07/19.77
Exc. Mg^{2+} cmol(1/2Mg^{2+}) kg^{-1}	Range	0.14 - 2.03	0.51 - 2.45	0.55 - 1.87	0.19 - 2.64	0.14 - 2.86	0.39 - 0.72	0.14 - 2.86
	Mean/S.D.	0.81/0.46	0.96/0.53	0.95/0.32	0.82/0.53	0.79/0.69	0.53/0.10	0.81/0.49

Table 4. Grade distribution of pH and exc. Ca^{2+} and Mg^{2+} in typical farmlands under tobacco-rice rotation in Xuancheng.

Region	pH			Exch. Ca^{2+} [cmol(1/2Ca^{2+}) kg^{-1}]			Exch. Ma^{2+} [cmol(1/2Mg^{2+} kg^{-1}]		
	Low (%)	Suitable (%)	High (%)	Low (%)	Suitable (%)	High (%)	Low (%)	Suitable (%)	High (%)
Xuanzhou	33.33	52.38	14.28	54.76	28.57	16.66	76.19	14.29	9.52
Langxi	72.73	18.18	9.09	90.91	0	9.09	54.55	36.36	9.09
Jingde	28.57	71.43	0	61.90	33.33	4.76	57.14	38.10	4.76
Jing	31.03	48.28	20.69	55.17	24.14	20.69	72.41	24.14	3.45
Guangde	46.15	53.85	0	69.23	23.08	7.69	84.62	7.69	7.69
Ningguo	37.50	62.50	0	75.00	25.00	0	100.00	0	0
Total	37.10	52.42	10.49	62.10	25.00	12.9	72.58	20.97	6.45

To the whole Xuancheng city, 37.10% (46 farmlands), 62.10% (77 farmlands) and 72.58% (90 farmlands) of the topsoil samples were in the low grades of pH, exc. Ca^{2+} and Mg^{2+}, respectively, which indicate these tobacco planting farmlands still need continuously apply dolomite powders. 52.42% (65 farmlands), 25.00% (31 farmlands) and 20.97% (26 farmlands) of the topsoil samples were in the suitable grades of pH, exc. Ca^{2+} and Mg^{2+}, respectively, which suggest these tobacco planting farmlands should postpone applying dolomite powders. 10.49% (13 farmlands), 12.90% (16 farmlands) and 6.45% (8 farmlands) of the topsoil samples were in the high grades of pH, exc. Ca^{2+} and Mg^{2+}, respectively, which prove these tobacco planting farmlands should immediately stop applying dolomite powders.

The severest low pH phenomenon occurred in Langxi county, 72.73% of its farmlands were in the low grade, meanwhile, there was little difference in other regions in low pH proportions of their farmlands, ranged from 31.03% to 46.15% of their total farmlands. The severest high pH phenomenon happened in Jing county, 20.69% of its farmlands were in the high grade, followed by Xuanzhou district and Langxi county, 14.28% and 10.49% of their total farmlands were in the high grade, meanwhile no farmland in Jingde county, Guangde county and Ningguo city in the high grade.

The severest low exc. Ca^{2+} phenomenon occurred in Langxi county, 90.91% of

its farmlands were in the low grade, followed by Ningguo city, 75.00% of its total farmlands were in the low grade. There was little difference in Jingde county, Jing county and Xuanczhou district in low exc. Ca^{2+} proportions of farmlands, ranged from 54.17% to 61.90% of their total farmlands. The severest high exc. Ca^{2+} phenomenon happened in Jing county, 20.69% of its farmlands were in the high grade, followed by Xuanzhou district, 16.66% of its total farmlands were in the high grade. There was little difference in other regions in low exc. Ca^{2+} proportions of farmlands, ranged from 4.76% to 9.09% of their total farmlands.

The severest low exc. Mg^{2+} phenomenon appeared in Ningguo city, all farmlands were in the low grade, followed by Guangde county, Xuanzhou district and Jing county, 84.62%, 76.19% and 72.41% of their total farmlands were in the low grade, meanwhile 54.55% and 57.14% of their total farmlands were in the low grade in Langxi county and Jingde county. No farmland was in the high grade in Ningguo city, while there was little difference in other regions in high exc. Mg^{2+} proportions of the farmlands, ranged from 3.45% to 9.52% of their total farmlands.

3.3. Relationship between Soil pH and Exc. Ca^{2+} and Mg^{2+}

The optimal regression models between soil pH and exc. Ca^{2+} and Mg^{2+} were established by using IBM Statistics SPSS20.0 (see **Figure 2**), the models show that pH had an extremely significantly positive Napierian logarithm correlation with exc. Ca^{2+} and an extremely significantly positive power correlation with exc. Mg^{2+}. The above equations prove that pH will increase fast initially but then increase slowly and tends to be stable with the increase of Ca^{2+} and Mg^{2+}, such a phenomenon is conform to the results in other studies [17] [18].

3.4. Estimation on Input and Output exc. Ca^{2+} and Mg^{2+} in Farmland

Exogenous Ca^{2+} and Mg^{2+} usually are input into the farmlands by fertilization and applying dolomite powders. According to the fertilization information [19], about 2.2 $kg{\cdot}hm^{-2}$ and 7.4 $kg{\cdot}hm^{-2}$ of Ca^{2+} are annually input into the farmlands by fertilization during tobacco-planting season and rice-planting season, respectively, while no Mg^{2+} in these fertilizers. About 336 $kg{\cdot}hm^{-2}$ of Ca^{2+} and 195 kg hm^{-2} of Mg^{2+} are input into the farmlands by applying dolomite powders 1500 $kg{\cdot}hm^{-2}$, thus, in total about 338.2 $kg{\cdot}hm^{-2}$ of Ca^{2+} and 202.4 $kg{\cdot}hm^{-2}$ of Mg^{2+} are annually input into the farmlands.

Ca^{2+} and Mg^{2+} usually are moved out of the farmlands by harvest of tobacco and rice. Tobacco leaves are harvested while tobacco stems are removed out from the farmlands to avoid disease spread. According to measured data of 62 tobacco samples collected from Xuancheng during 2007-2008, the average concentrations of Ca^{2+} and Mg^{2+} are 17.0 $g{\cdot}kg^{-1}$ and 2.8 $g{\cdot}kg^{-1}$, respectively with the total biomass of 4500 $kg{\cdot}hm^{-2}$ (tobacco leaves plus stems), thus, about 76.5 $kg{\cdot}hm^{-2}$ of Ca^{2+} and 12.6 $kg{\cdot}hm^{-2}$ of Mg^{2+} are annually removed out from the

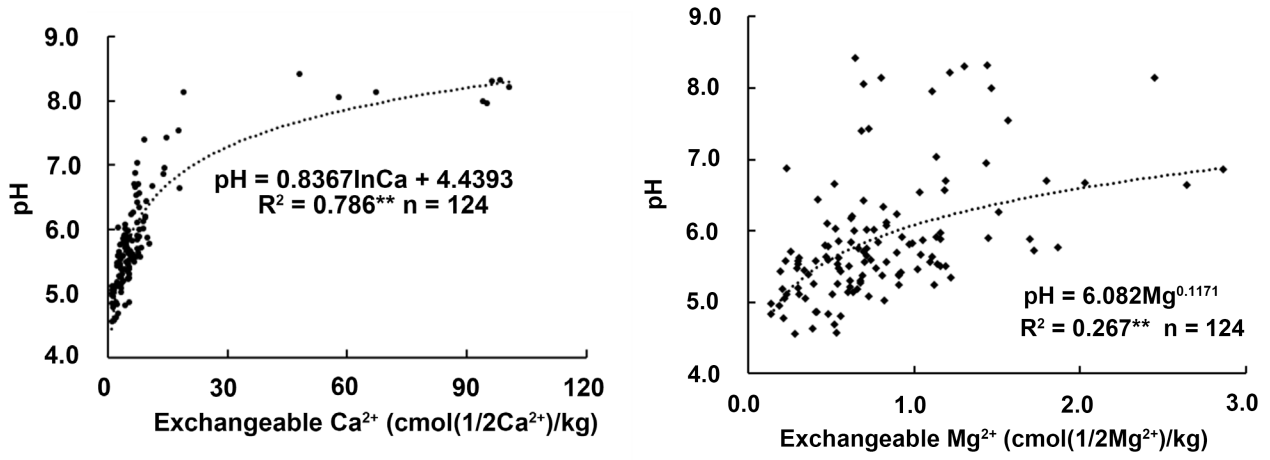

Figure 2. Correlations between soil pH and exc. Ca^{2+} and Mg^{2+} of farmlands under tobacco-rice rotation in Xuancheng.

farmlands. The average concentrations of Ca^{2+} and Mg^{2+} are about 0.3 g·kg^{-1} and 0.8 g·kg^{-1} in rice ears [20] [21] with the total rice-ear biomass of 7500 kg·hm^{-2}, thus, about 0.2 kg·hm^{-2} of Ca^{2+} and 0.6 kg·hm^{-2} of Mg^{2+} are annually removed out from the farmlands, thus, in total, about 17.2 kg·hm^{-2} of Ca^{2+} and 13.2 kg·hm^{-2} of Mg^{2+} are annually carried out from the farmlands.

According to the above data, the net annual increase of Ca^{2+} and Mg^{2+} in the farmlands are 321.0 kg·hm^{-2} and 188.9 kg·hm^{-2}, respectively, which prove the application of dolomite powders not only promote pH of farmlands, but also simultaneously increase exc. Ca^{2+} and Mg^{2+} of farmlands.

Over high pH and exc. Ca^{2+} or Mg^{2+} is unsuitable for tobacco planting, further data analysis roughly showed that the farmlands with 3 times or more application of dolomite powders usually are potential in the high grades of pH, exc. Ca^{2+} and Mg^{2+}. So it is necessary to monitor the farmlands dynamically in order to decide whether continuous applying dolomite powders which should be dependent upon the specific conditions of individual farmlands.

4. Conclusion

Our survey showed that the application of dolomite powders really increased soil pH and supplied Ca and Mg nutrients in the farmland under tobacco-rice rotation, however, 40% - 70% of the farmlands still were in low pH and exc. Ca^{2+} and Mg^{2+} which need continuous applying dolomite powders, meanwhile 6% - 13% of the farmlands were in high pH and exc. Ca^{2+} and Mg^{2+} which should stop applying dolomite powders immediately, whether continuous applying dolomite powders should be dependent upon the specific conditions of individual farmlands.

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