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Improving the Facility Soil by Combining Soil Amendment with Agronomic Measures

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Abstract [**Objectives**] To study the remediation methods of secondary salinization and cadmium pollution in facility soil. [**Methods**] Two kinds of soil amendments, potassium fulvic acid and limestone powder, were selected to be applied alone or combined together to plant maize to carry out field experiments. Their effects on watermelon yield, watermelon cadmium content, soil available nitrogen, phosphorus, potassium and water-soluble salts were studied. [**Results**] The application of potassium fulvic acid, limestone powder and their combined application increased the yield and soluble solids of watermelon to different degrees. The contents of seven heavy metals including cadmium, copper, zinc, arsenic, lead, mercury and chromium in the watermelon of all treatments were all lower than the food safety limit stipulated in the national standard. During the harvest period of maize seedlings, all treatments could increase soil pH and decrease soil cadmium availability. In particular, 3 000 kg/ha of limestone powder and 1 500 kg/ha of potassium fulvic acid had the best effect on reducing soil available cadmium content. In reducing soil available cadmium content, there were significant differences between single application of amendment and combined application treatments. In addition, compared with the control CK, all treatments decreased soil available nitrogen, phosphorus, potassium and water-soluble salt content. [**Conclusions**] Potassium fulvic acid, limestone powder and their combined application can increase the yield of watermelon, and can significantly reduce the available cadmium, nitrogen, phosphorus, potassium and water-soluble salt content in the facility soil of maize cultivation.

Key words Facility soil, Secondary salinization, Agronomic measures, Cadmium

1 Introduction

China has become a large producer of facility agriculture, ranking first in the world in terms of both area and output. At present, the planting area of China's facility agriculture has exceeded 85% of the world's facility agriculture planting area. Facility agriculture is the main direction of future agricultural development[1]. The large-scale construction of facility agriculture has brought considerable benefits. However, due to its own constraints, the soil lacks rainwater washing, and the temperature, ventilation, humidity and fertilizer are quite different from those of traditional open field cultivation. In addition, facility agriculture itself is characterized as high intensification, high multiple cropping rate, and high fertilization rate. These lead to a series of soil degradation problems such as soil acidification, soil secondary salinization, and heavy metal pollution[2-3]. Soil degradation will lead to soil compaction, poor fertility, decreased microbial activity, reduced yield and quality of agricultural products, and other hazards, accordingly influencing the ecological environment and human health. In recent years, some scholars have studied the soil degradation problems of facility cultivation, such as secondary salinization, heavy metal pollution, and soil acidification[4-6]. However, due to the geographical differences of facility agricultural ecosystems, studies on acidification, secondary salinization and heavy metal pollution of facility soil in Guangxi are rarely reported, and there is a lack of targeted research. In view of these, taking the facility horticultural soil in Guangxi as the research object, we explored the effects of different amendments combined with agronomic measures on facility soil pH, soil available cadmium, water-soluble salt content and watermelon quality, so as to provide a scientific basis for the degradation and improvement of facility soil in Guangxi, and promote the sustainable and healthy development of the facility horticulture industry.

2 Materials and methods

2.1 Experimental site and materials The experimental site is located in the main production area of facility agriculture in Beihai City of Guangxi. The planting period of the greenhouse is 17 years, and the soil is the red soil developed by the Quaternary marine parent material. Its agrochemical properties are as follows: soil pH 5.10, organic matter 30.0 g/kg, alkaline hydrolyzable nitrogen 310 mg/kg, available phosphorus 442 mg/kg, available potassium 191 mg/kg, total cadmium 0.23 mg/kg, available cadmium 0.070 mg/kg, total lead 3.7 mg/kg, total chromium 31.7 mg/kg, total mercury 0.103 mg/kg, total arsenic 10.9 mg/kg, total copper 46 mg/kg, total zinc 108 mg/kg, and water-soluble salt 2.16 g/kg. The experimental crop is watermelon (No.5) and maize (Guidan 166). The experimental amendments include limestone powder and potassium fulvic acid. The limestone powder is

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900 mesh limestone powder with pH 9.90, total cadmium 0.079 mg/kg, total lead 21.20 mg/kg, total chromium 87.40 mg/kg, total mercury 0.23 mg/kg, total arsenic 3.50 mg/kg, total copper 25.10 mg/kg, and total zinc 97 mg/kg; the potassium fulvic acid comes from molasses, with pH 6.5, organic matter 75.80%, total nitrogen 3.58%, total phosphorus (P_2O_5) 0.23%, total potassium (K_{20}) 10.40%, total cadmium 0.129 mg/kg, total lead 0.812 mg/kg, total chromium 2.88 mg/kg, total mercury 0.12 mg/kg, total arsenic 0.82 mg/kg, total copper 6.50 mg/kg, and total zinc 458 mg/kg.

2.2 Experimental design On the basis of applying the same amount of chemical fertilizers nitrogen, phosphorus and potassium, we set 9 treatments, namely: (a) control (CK), (b) limestone powder 1 500 kg/ha, (c) limestone powder 3 000 kg/ha, (d) potassium fulvic acid 750 kg/ha, (e) potassium fulvic acid 1 500 kg/ha, (f) limestone powder 1 500 kg/ha + potassium fulvic acid 750 kg/ha, (g) limestone powder 1 500 kg/ha + potassium fulvic acid 1 500 kg/ha, (h) limestone powder 3 000 kg/ha + potassium fulvic acid 750 kg/ha, (i) limestone powder 3 000 kg/ha + potassium fulvic acid 1 500 kg/ha, denoted as CK, TR1, TR2, TR3, TR4, TR5, TR6, TR7 and TR8, respectively. The plot area was 26 m^2, each treatment was repeated 3 times and the plots were randomly arranged. Limestone powder and potassium fulvic acid were applied one time as base fertilizer, and the experimental field management was the same as that in the field. In the first cropping season, watermelons were planted with a row spacing of 110 cm and a plant spacing of 40 cm. Each plot was planted with 2 rows and 60 plants. The planting time was March 9, 2020, and the harvesting time was May 28. After harvest, we measured the yield of melons in each plot. In the second cropping season, maize was not planted in control CK, but planted in all other treatments. The planting specifications were 40 cm row spacing, 25 cm plant spacing, and 2 seeds per hole. At the 3-leaf stage of maize, 1 plant was thinned and 1 plant was for final signaling, 4 rows were planted in each plot, and 192 plants were cultivated. The planting time was June 13, 2020, and maize seedlings were collected on July 23 and ploughed and returned to the field.

2.3 Sample collection and analysis Before the experiment, we collected samples of the surface soil 0 – 20 cm using S method. After the experiment (collecting maize seedlings), we collected samples of 0 – 20 cm deep soil in each plot. Took 1 kg of the mixed soil according to the quartering method, air dried in the room, pulverized, sieved (2 mm), and stored for experiment. From each plot, we collected 6 watermelons at the maturity stage for quality analysis.

Soil pH was measured by acidity meter method (soil-water ratio 1∶5); the water-soluble salt was determined by the mass method (soil-water ratio 1∶5); the alkaline hydrolysis nitrogen was determined using the alkaline hydrolysis diffusion method; the available phosphorus was determined by 0.5 mol/L $NaHCO_3$ extraction- molybdenum antimony anti-colorimetric method; the available potassium was determined by NH_4OAc extraction-flame photometry; the organic matter was determined using the potassium dichromate volumetric method; total nitrogen was determined by Kjeldahl method; total phosphorus was determined by sodium hydroxide fusion-molybdenum antimony anti-colorimetric method; total potassium was determined by sodium hydroxide fusion-flame photometer method. Watermelon soluble solids were determined by digital saccharometer method. Heavy metals were detected according to the first method specified in the *National Food Safety Standard: Determination of Multi-elements in Foods* (GB5009.268-2016). Other analytical items were determined by conventional analytical methods.

2.4 Data analysis With the aid of SPSS 21.0 software, we conducted one-way ANOVA and *LSD* multiple comparisons to test the degree of difference between different treatments and conduct statistical analysis of related data. Different lowercase letters in the paper indicate statistical significance ($P<0.05$).

3 Results and analysis

3.1 Effects of amendments on yield and solids of watermelon The effects of different treatments on yield were listed in Table 1, different treatments had significant differences. Compared with the control CK, the yield of the treatment with the amendments increased, and the yield increased by 0.87% – 15.24%. In TR3 treatment, potassium fulvic acid 750 kg/ha had little effect on yield. The treatments of limestone powder 1 500 kg/ha and limestone powder 3 000 kg/ha significantly increased the yield of watermelon. Compared with the CK, the yield was higher by 14.65% and 15.24%, respectively. The yields of watermelon treated with limestone powder alone or in combination with potassium fulvic acid were higher than those treated with potassium fulvic acid alone. In particular, the yield of TR2 limestone powder 3 000 kg/ha treatment was the highest, which was 25 296.90 kg/ha.

The soluble solids of different treatments were shown in Table 1, and the difference between treatments was not significant. Compared with the control CK, the water-soluble solids of the watermelon treated with the amendment increased by 5.05% – 10.53%. The soluble solid content of watermelon treated with TR5 limestone powder 1 500 kg/ha + potassium fulvic acid 750 kg/ha was the highest, which was 15.33%, followed by TR2 limestone powder 3 000 kg/ha, which was 15.07%.

Table 1 Yield and water-soluble solids of watermelon treated with different amendments

Treatment	Yield//kg/ha	Water-soluble solids//%
CK	21 952.35 ±591.00 c	13.87 ±0.32 a
TR1	25 169.40 ±1 043.10 a	14.57 ±0.58 a
TR2	25 296.90 ±1 330.50 a	15.07 ±0.85 a
TR3	22 142.70 ±500.70 c	14.63 ±0.32 a
TR4	22 726.80 ±1 764.00 bc	14.97 ±0.80 a
TR5	23 418.00 ±1 530.60 abc	15.33 ±0.64 a
TR6	23 364.00 ±265.20 abc	14.83 ±0.91 a
TR7	22 833.00 ±384.00 bc	14.77 ±1.12 a
TR8	24 702.15 ±1 864.65 ab	14.70 ±0.89 a

Note: Different lowercase letters after the data in the same column in the table indicate significant differences, the same below.

3.2 Effects of amendments on heavy metal content in watermelon Heavy metal content of watermelon in different treatments was indicated in Table 2. The contents of seven heavy metals in watermelon of each treatment were lower than the national food safety limit standard (GB2726-2017). Compared with CK, the treatment with limestone powder TR1 had high cadmium content, while the cadmium content of watermelon in the other treatments with amendments decreased. The reduction range was 14.80% - 17.76%, and the treatment effect of applying potassium fulvic acid 1 500 kg/ha was the best. Compared with the control CK, the copper content of watermelon in the TR5, TR6 and TR8 treatments increased by 32.76% -57.47%, while the copper content of other treatments was lower than that of the control CK. Compared with CK, the zinc content of watermelon in TR6 and TR7 treatments increased by 10.78% and 16.18%, respectively. The arsenic content in watermelon was the lowest in the TR3 treatment, which was 42.75% lower than that in the control CK treatment. Compared with CK, there were both increase and decrease in the content of heavy metals cadmium, copper, zinc and arsenic in watermelon treated with amendments, which may be related to the total amount and properties of heavy metals cadmium, copper, zinc and arsenic in the amendments applied.

Table 2 Heavy metal content of watermelon treated with different amendments (mg/kg)

Treatment	Cd	Cu	Zn	As	Pb	Hg	Cr
CK	0.004 73 ±0.000 82 b	0.348 ±0.005 d	2.04 ±0.12 b	0.004 07 ±0.000 05 b	ND	ND	ND
TR1	0.005 28 ±0.000 56 a	0.158 ±0.009 g	1.84 ±0.06 c	0.003 66 ±0.000 06 c	ND	ND	ND
TR2	0.004 03 ±0.000 46 d	0.307 ±0.006 e	1.40 ±0.07 d	0.004 06 ±0.000 04 b	ND	ND	ND
TR3	0.002 38 ±0.000 42 h	0.439 ±0.009 d	1.77 ±0.08 c	0.002 33 ±0.000 05 f	ND	ND	ND
TR4	0.003 89 ±0.001 14 e	0.247 ±0.008 f	2.02 ±0.09 b	0.003 32 ±0.000 06 e	ND	ND	ND
TR5	0.004 36 ±0.000 66 c	0.464 ±0.006 b	1.78 ±0.04 c	0.003 61 ±0.000 09 c	ND	ND	ND
TR6	0.003 33 ±0.000 61 f	0.548 ±0.009 a	2.26 ±0.07 a	0.003 43 ±0.000 06 d	ND	ND	ND
TR7	0.003 06 ±0.000 40 g	0.317 ±0.007 e	2.37 ±0.07 a	0.004 16 ±0.000 06 b	ND	ND	ND
TR8	0.003 34 ±0.000 51 f	0.462 ±0.006 b	1.83 ±0.08 c	0.005 14 ±0.000 07 a	ND	ND	ND
Food safety limit	0.05	3	20	0.5	0.1	0.01	0.5

Note: ND denotes not detected in accordance with *National Food Safety Standard Contamination Limit in Food* (GB2762-2017).

3.3 Effects of different treatments on soil pH and available cadmium The adsorption of heavy metal cadmium in soil weakened with the decrease of pH, but the mobility increased. With the pH increase, the ability of soil to adsorb heavy metal cadmium was enhanced, and the precipitation of metal cadmium with carbonate and hydroxide or the adsorption and complexation of organic matter, the effectiveness of cadmium in soil decreased. From Table 3, it can be seen that the pH of the soil treated with the amendments at the maize seedling harvesting period was higher than that of the soil treated with CK, and the two amendments and their combined application achieved the purpose of increasing the soil pH, which may be related to the fact that the two modifiers belong to organic matter, high potassium content or alkaline materials. Among them, the treatment of TR2 limestone powder 3 000 kg/ha had the largest increase in pH, which was 1.12 units higher than that of CK, followed by the treatment of TR1 limestone powder 1 500 kg/ha, which was higher than CK by 1.00 units. All treatments at the harvest period of maize seedlings could reduce the availability of soil cadmium. Among them, TR2 limestone powder 3 000 kg/ha and TR3 potassium fulvic acid 750 kg/ha had the best effect on reducing soil available cadmium content. In reducing soil available cadmium content, there were significant differences between single application of amendment and its combined application. After applying different amendments, soil pH and available Cd content showed a negative correlation, but the difference was not significant, and the correlation coefficient r was -0.354 ($P = 0.070$, $n = 21$). Apart from the effects of adsorption, desorption, redox, *etc.* on the effective state of soil heavy metal Cd, the effect of amendments on soil pH is also an important mechanism. The increase of soil pH, on the one hand, increases the variable negative charge on the soil surface, promotes the adsorption of heavy metal ions by soil colloids, and reduces the desorption of adsorbed heavy metals; on the other hand, due to the decrease in the concentration of hydrogen ions in the solution, the competition effect of hydrogen ions is weakened. As the main carrier for soil adsorption of heavy metals, such as carbonate, organic matter and iron and manganese oxides, hydrogen ions bind more firmly with heavy metals, thereby making heavy metals reduce the bioavailability[7].

Table 3 Soil pH and available cadmium content treated with different amendments

Treatment	Soil pH in harvest period	Soil available cadmium in harvest period//mg/kg
CK	5.12 ±0.10 d	0.067 ±0.006 a
TR1	6.12 ±0.06 a	0.047 ±0.003 cd
TR2	6.16 ±0.21 a	0.044 ±0.004 d
TR3	5.14 ±0.02 d	0.042 ±0.003 d
TR4	5.06 ±0.04 d	0.051 ±0.003 bc
TR5	5.2 ±0.12c d	0.055 ±0.002 b
TR6	5.37 ±0.10 c	0.052 ±0.002 bc
TR7	5.78 ±0.05 b	0.048 ±0.003 cd
TR8	5.78 ±0.11 b	0.052 ±0.002 bc

3.4 Effects of different treatments on soil available nutrients and water-soluble salt content The contents of soil available nutrients and water-soluble salts in different treatments at the harvest period of maize seedling s are shown in Table 4. There were significant differences between treatments. Compared with the control CK, the content of soil available nutrients and water-soluble salts in the combined treatment of maize with amendments decreased, and the soil available nutrients nitrogen, phosphorus, potassium and water-soluble salts decreased by 47.80% – 70.75%, 7.71% – 39.83%, 4.89% – 55.43% and 34.84% – 66.06%, respectively. Compared with the control CK, the content of alkali-hydrolyzed nitrogen in the soil treated with the seed amendments decreased more than the content of available phosphorus and potassium in the soil treated with the seed amendments, which may be related to the absorption of nitrogen in maize seedling stage.

Table 4 Contents of soil available nutrients and water-soluble salts treated with different amendments

Treatment	Alkaline hydrolyzed nitrogen//mg/kg	Available phosphorus//mg/kg	Available potassium//mg/kg	Water-soluble salts//g/kg
CK	318 ± 12 a	467 ± 13 a	184 ± 8 a	2.21 ± 0.06 a
TR1	126 ± 3 d	281 ± 11 e	82 ± 5 d	1.16 ± 0.05 c
TR2	93 ± 8 e	305 ± 14 d	112 ± 5 c	0.83 ± 0.04 e
TR3	126 ± 8 d	284 ± 14 e	120 ± 9 c	0.77 ± 0.03 e
TR4	142 ± 11 cd	382 ± 9 c	142 ± 7 b	0.75 ± 0.04 e
TR5	131 ± 8 d	412 ± 17 b	114 ± 8 c	0.83 ± 0.03 e
TR6	166 ± 13 b	431 ± 13 b	139 ± 9 b	1.05 ± 0.01 d
TR7	150 ± 5 c	385 ± 6 c	175 ± 5 a	1.12 ± 0.06 cd
TR8	127 ± 11 d	324 ± 11 d	117 ± 1 c	1.44 ± 0.06 b

4 Conclusions

(i) Application of potassium fulvic acid, limestone powder and their combined application treatments can increase the yield of watermelon to different degrees. In particular, the yield of watermelon treated with limestone powder 3 000 kg/ha had the largest increase. The soluble solid content of watermelon treated with limestone powder 1 500 kg/ha + potassium fulvic acid 750 kg/ha was the highest.

(ii) Compared with the control CK treatment, single application of potassium fulvic acid, limestone powder and their combined application treatments increased or decreased the contents of cadmium, copper, zinc and arsenic in watermelon. The contents of 7 heavy metals of all treatments were lower than the national food safety limit standard.

(iii) The single application of the amendment and its combined application of maize treatment can increase the soil pH and reduce the bioavailability of Cd in the soil. After the combined planting of maize with different amendments, the soil pH and available Cd content were negatively correlated. The higher the pH, the lower the available Cd content of the soil.

(iv) In the maize seedling harvest period, the contents of soil available nitrogen, phosphorus, potassium and water-soluble salts decreased in the single application of different amendments and their combined application.

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