Application of Tebeca soil conditioner can increase vegetable yield and reduce heavy metal accumulation in red soil region

Dongfeng Huang1,4, Zhucai Pan2 and Xiaoxuan Qiu1,3

1Institute of Soil and Fertilizer, Fujian Academy of Agricultural Sciences; 2Nan'an Institute of Agricultural Sciences, Fujian Province; 3Fujian Key Laboratory of Agro-products Quality & Safety

Email: huangdf@189.cn

Abstract. A field plot trial was conducted to study the effects of applying different dosages of Tebeca soil conditioning (i.e., 750 kg/hm², 1500 kg/hm², 2250 kg/hm² and 3000 kg/hm²) on the yield, Cd and Pb contents of vegetable, soil acidity and available heavy metal Cd and Pb contents in soil. Results showed that: Compared with the treatment without using soil conditioner, the application of different dosage of Tebeca soil conditioning could increase vegetable yield by 9.2%~43.8%, decrease Cd content by 13.3%~68.0%, Pb content by 12.4%~71.1%, increase soil pH by 2.7%~17.6%, decrease exchangeable hydrogen by 7.4%~42.2%, exchangeable aluminium by 20.5%~55.4%, respectively. Meanwhile, the content of available Cd and Pb in soil were reduced by 15.6%~66.1% and 3.6%~34.7% respectively. Among them, the application effect of Tebeca soil conditioning agent in vegetable production was better when it was applied from 2250 kg/hm² to 3000 kg/hm².

1. Introduction

The total area of red soil region in southern China is 1.2×106 km², which accounts for 12% of the total land area in China [1]. The region is rich in water and heat resources and has great potential for production. It occupies an extremely important position in the development of agriculture, economy and society in China. However, due to the dual effects of natural conditions such as high temperature and rainy, unreasonable high-intensity development and other human factors, especially in recent years, due to the aggravation of acid deposition hazards and the extensive application of physiological acidic fertilizers [2], soil acidification has become increasingly serious, and heavy metal pollution of agricultural products caused by soil heavy metal activation has also occurred from time to time, which has seriously hindered the sustainable and efficient utilization of farmland soil in this area.

Although the application of lime can alleviate the problem of soil acidification, long-term application of lime can easily lead to the consolidation of farmland soil, which is not conducive to crop growth [3]. With the progress of science and technology, in order to solve the problem of acidification and passivation of heavy metals in farmland soils, a series of acidified soil conditioners emerged. However, at present, the preparation of soil conditioner products is complicated and expensive, which limits its large-scale production and wide application [4]. Therefore, the research and development of acidic soil conditioner products with abundant resources, simple preparation and reasonable price still need to be further strengthened in the future.

Tebeca soil conditioner product is a new type of soil conditioner, which is made from seafood waste (oyster shell) with abundant coastal resources in China. It is processed by advanced "protective
baking and fractional activation process and particle size separation process. The new soil conditioning agent retains the organic nutrients of oyster shell to the greatest extent on the basis of obtaining calcium oxide, and has the characteristics of uniform granulation (0.28mm) and large specific surface area [5,6]. It is an excellent acid soil conditioning product. It has been reported that the application of Tebeca soil conditioner products on acid soils in red soil region can obviously increase the yield of peanut and San-qi and alleviate soil acidification [7,8] but the application effect on other crops is seldom reported. Therefore, in this paper, a field plot trial was conducted to study the effects of Tebeca soil conditioner on vegetable yield, heavy metal (Cd, Pb) content, soil acidity and available heavy metal (Cd, Pb) content of vegetables in red soil region by planting two successive crops of vegetables (Pakchoi and Water spinach) in order to control acidified soil in red soil region and to improve vegetable yield and quality. The aim is to provide scientific basis for the treatment of acidified soil in red soil region and the production of high-yield and high-quality vegetable products.

2. Materials and methods

The experiment was conducted at a vegetable planting base in Gaiwei Town, Xianyou County, Fujian Province. The topography and physiography are mainly low hills and flat land, with an average altitude of 40 m. The marine monsoon climate in the south subtropical zone has no severe summer, no severe cold in winter, abundant sunshine and abundant rainfall, with an average annual precipitation of 1700 mm and an average annual temperature of 23.1℃. The soil type of the experimental plot is grey yellow mud vegetable garden soil. The basic physical and chemical properties of the soil are: pH 4.5, organic matter content 14.26 g/kg, total nitrogen content 0.64 g/kg, total phosphorus content 0.39 g/kg, available phosphorus content 23.35 mg/kg, available potassium content 83 mg/kg, Cd content 0.38 mg/kg, and Pb content 88 mg/kg.

Five treatments were designed, namely, 1) habitual fertilization (N 180 kg/hm², P₂O₅ 72 kg/hm², K₂O 90 kg/hm², the same below), 2) habitual fertilization + Tebeca soil conditioner 750 kg/hm², 3) habitual fertilization + Tebeca soil conditioner 1500 kg/hm², 4) habitual fertilization + Tebeca soil conditioner 2250 kg/hm², 5) habitual fertilization + Tebeca soil conditioner 3000 kg/hm². T₀, T₁, T₂, T₃ and T₄ were used respectively. Each treatment was repeated three times. Each plot has an area of 20 m² and is arranged in random groups. The fertilizer varieties and Tebeca soil conditioners used are as follows: Urea (N 46%), Monoammonium phosphate (N 10%, P₂O₅ 50%), Potassium chloride (K₂O 60%), Tebeca soil conditioner (CaO > 45%, pH=8.5~10.5), produced by Fujian Mata Agricultural Development Co., Ltd. Fertilizers and Tebeca soil conditioners applied in all treatments were combined with soil preparation as base fertilizer.

The vegetable varieties and field management were as follows: the first stubble, Brassica rapa chinensis, sown on March 30, 2018, harvested, sampled and measured production on May 18; the second stubble, Ipomoea aquatica, Thai Golden Axe, sown on May 30, 2018, harvested, sampled and measured production on July 10.

The basic physical and chemical properties of soil were determined by conventional methods of soil agrochemical analysis [9]: pH value was determined by Potentiometric method (soil-water ratio 1:2.5); organic matter was determined by potassium dichromate volumetric method; total nitrogen was determined by semi-micro Kelvin method; total phosphorus was determined by molybdenum blue colorimetry; total potassium was determined by flame photometry; alkaline nitrogen was determined by alkaline hydrolysis diffusion method; extraction of effective phosphorus with 0.05 mol·L⁻¹ NaHCO₃ and determination of effective phosphorus by Molybdenum Blue Colorimetry; Flame photometric determination of available potassium; Determination of heavy metals Cd and Pb in vegetables by HNO₃-H₂O₂ microwave Digestion-Graphite Furnace Atomic Absorption spectrometry. The contents of Cd and Pb in soil were determined by DTPA Extraction-Atomic Absorption Spectrophotometry [10]. The exchangeable acidity of soil was determined by potassium chloride extraction-titration (HJ 649-2013) [11]. In the process of sample determination, the quality control of the whole digestion and analysis process was carried out by using national standard material samples (GBW 10014-cabbage and GBW 07405-soil national standard material).
3. Results and analysis

3.1. Effect of applying different dosage of Tebeca soil conditioner on vegetable yield

Results (Table 1) showed that, compared with the treatment without using soil conditioner (T0), the application of different amounts of Tebeca soil conditioner treatments (i.e., T1, T2, T3 and T4) could increase vegetable yield to a certain extent. The yield of the first and second crop of Pakchoi and Water spinach increased by 11.0%~43.8% and 9.2%~41.8%, respectively. Among them, T3 and T4 treatments had better effect on vegetable yield. The results of variance analysis showed that the effect of T3 treatment was extremely significantly better than that of T1 and T0 treatment (P < 0.01), and significantly better than that of T2 treatment (P < 0.05), but there was no significant difference between T4 treatment and T3 treatment (P > 0.05). For the second crop of water spinach, T3 treatment was extremely significantly superior to T2, T1 and T0 treatment (P < 0.01), and significantly superior to T4 treatment (P < 0.05), while T4 treatment was also extremely significantly superior to T2, T1 and T0 treatment (P < 0.01).

Table 1. Effects of applying different dosages of Tebeca soil conditioner on vegetable yield.

| Treatment | Pakchoi Yield(kg/hm²) | Increase rate(%) | Water spinach Yield(kg/hm²) | Increase rate(%) |
|-----------|------------------------|-----------------|-----------------------------|-----------------|
| T0        | 11098.6Bc              | \               | 9862.3Cd                    | \               |
| T1        | 12320.8Bc              | 11.0            | 10768.8BCd                  | 9.2             |
| T2        | 14678.6Ab              | 32.3            | 11876.5Bc                   | 20.4            |
| T3        | 15964.2Aa              | 43.8            | 13986.7Aa                   | 41.8            |
| T4        | 15097.5Aab             | 36.0            | 12967.8Ab                   | 31.5            |

Note: Different upper and lower-case letters after the same column values in the table show significant differences (P < 0.01) and significant levels (P < 0.05), respectively, the same below.

3.2. Effects of applying different dosages of Tebeca soil conditioner on heavy metal content in vegetables

Table 2. Effects of applying different dosages of Tebeca soil conditioner on heavy metals’ content in vegetables.

| Treatment | Cd(mg/kg) Increase rate(%) | Pb(mg/kg) Increase rate(%) | Cd(mg/kg) Increase rate(%) | Pb(mg/kg) Increase rate(%) |
|-----------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| T0        | 0.437Aa                     | \                           | 0.501Aa                     | \                           |
| T1        | -0.379Ab                    | -13.3                       | 0.439Ab                     | -12.4                       |
| T2        | -0.301Bc                    | -31.1                       | 0.328Bc                     | -34.5                       |
| T3        | -0.197Cd                    | -54.9                       | 0.254Cd                     | -49.3                       |
| T4        | -0.218Cd                    | -50.1                       | 0.289Cd                     | -42.3                       |

Results (Table 2) showed that, compared with the treatment without using soil conditioner (T0), the application of different amounts of Tebeca soil conditioner treatments (i.e., T1, T2, T3 and T4) could reduce the contents of Cd and Pb in vegetables to a certain extent. The contents of Cd and Pb in the first crop of pakchoi decreased by 13.3%~54.9% and 12.4%~49.3% respectively, and the contents of Cd and Pb in the second crop of water spinach decreased by 25.4%~68.0% and 24.7%~71.1% respectively. Among them, T3 and T4 treatments had a better effect on reducing the contents of Cd and
Pb in vegetables. The results of variance analysis showed that T₃ and T₄ treatments were extremely significantly better than those of T₂, T₁ and T₀ treatments for the reduction of Cd and Pb contents in the first crop of vegetable ($P < 0.01$), but there was no significant difference between T₃ and T₄ treatments, and T₂ treatments were also significantly better than those of T₁ and T₀ treatments; T₃ and T₄ treatments were significantly better than those of T₂, T₁ and T₀ treatments for the reduction of Cd contents in the second crop of vegetable. However, there was no significant difference between T₃ and T₄ treatments. T₄, T₃ and T₂ treatments were significantly better than T₁ and T₀ treatments in reducing heavy metal Pb content in the second crop of vegetable, but there was no significant difference between the three treatments.

3.3. Effects of applying different dosages of Tebeca soil conditioner on soil pH and exchangeable acidity after vegetable harvest

Results (Table 3) showed that, compared with the treatment without using soil conditioner (T₀), the application of different amounts of Tebeca soil conditioner treatments (i.e., T₁, T₂, T₃ and T₄) could increase the soil pH value after two crops of vegetable harvesting by 2.7%~17.6%, and reduce the exchangeable hydrogen and exchangeable aluminum content of soil by 7.4%~42.2% and 20.5%~55.4% respectively. Among them, T₃ and T₄ treatments had the best effect on improving soil pH value and reducing exchangeable aluminum content after vegetable harvest, which was extremely significantly superior to other treatments ($P < 0.01$), but the difference between T₃ and T₄ treatments was not significant; T₄ and T₃ treatments had the best effect on reducing exchangeable hydrogen content in soil after vegetable harvest ($P < 0.01$), and T₄ treatments were superior to T₃ treatment ($P < 0.05$).

Table 3. Effects of applying different dosages of Tebeca soil conditioner on soil pH and exchangeable acidity after vegetable harvest.

| Treatment | pH Value | pH Increase rate(%) | Exchangeable hydrogen Increase rate(%) | Exchangeable aluminum Increase rate(%) |
|-----------|----------|---------------------|----------------------------------------|---------------------------------------|
| T₀        | 4.43Bb   | \                  | 5.38Aa                                | 39.5Aa                                |
| T₁        | 4.55Bb   | 2.7                | 4.98Aa                                | 31.4ABb                               |
| T₂        | 4.72Bb   | 6.5                | 4.21Ab                                | 26.6Bb                                |
| T₃        | 5.15Aa   | 16.3               | 3.85Bc                                | 18.7Cc                                |
| T₄        | 5.21Aa   | 17.6               | 3.11Bd                                | 17.6Cc                                |

3.4. Effects of applying different dosages of Tebeca soil conditioner on available heavy metals’ content in soil after vegetable harvest

Table 4. Effects of applying different dosages of Tebeca soil conditioner on available heavy metals’ content in soil after vegetable harvest.

| Treatment | Available Cd (mg/kg) | Available Pb (mg/kg) |
|-----------|----------------------|----------------------|
| T₀        | 0.301Aa              | \                    |
| T₁        | 0.254ABa             | -15.6                |
| T₂        | 0.201Bb              | -33.2                |
| T₃        | 0.102Cc              | -66.1                |
| T₄        | 0.138Cc              | -54.2                |

Results (Table 4) showed that the available Cd and Pb contents of soil after two crops of vegetable harvesting were reduced by 15.6%~66.1% and 3.6%~34.7% respectively by applying different amounts of Tebeca soil conditioner treatments (i.e., T₁, T₂, T₃ and T₄) compared with those of non-
Tebeca soil conditioner treatments ($T_0$). Among them, $T_3$ and $T_4$ treatments had the best effect on reducing soil available Cd and Pb content after two crops of vegetable harvest, which was significantly better than other treatments ($P < 0.01$ or $P < 0.05$), but the difference between $T_3$ and $T_4$ treatments was not significant.

4. Discussion
Due to the excessive application of chemical fertilizers, the soil acidification and the activity of heavy metals in the red soil region of southern China have been aggravated, which has seriously hindered the improvement of crop yield and quality in the region [7, 12]. The soil conditioning agent of Tebeca used in this experiment is through reasonable temperature control and particle size grading. On the basis of obtaining calcium oxide, the organic matter and trace nutrient elements of oyster shell are retained to the greatest extent, and the pH value of the product is 8-10 [8, 13]. Therefore, the application of Tebeca soil conditioner on crops in red soil region can bring in more calcium, organic matter and trace nutrient elements, and significantly improve the soil pH, passivation of soil heavy metal activity, which can significantly improve crop yield and reduce the heavy metal content of agricultural products.

5. Conclusions
The trial results showed that, compared with the treatment without using soil conditioner ($T_0$), the application of different amounts of Tebeca soil conditioner treatments (i.e., $T_1$, $T_2$, $T_3$ and $T_4$) could increase vegetable yield by 9.2%~43.8%, reduce the Cd content of vegetables by 13.3%~68.0%, Pb content by 12.4%~71.1%, and increase the soil pH value by 2.7%~17.6%, and reduce the exchangeable hydrogen and exchangeable aluminum by 7.4%~42.2% and 20.5%~55.4%, respectively, while reducing soil available Cd and Pb content by 15.6%~66.1% and 3.6%~34.7%, respectively. Among them, $T_3$ and $T_4$ treatments were better for vegetable production.

Acknowledgments
This work was supported by several projects, which included Fujian Provincial Public Welfare Research Institute Basic Research Project(2018R1022-4), Fuzhou Science and Technology Project(2018-G-65), and Fujian Provincial Academy of Agricultural Sciences Science and Technology Innovation Team Project(STIT2017-2-10).

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