Effect of applying straw of Solanum photeinocarpum and their hybrids on nutrient of lettuce and soil under cadmium stress

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Abstract. In this study, the straw of Solanum photeinocarpum and their hybrids were applied. The effect of applying straw on nutrient of lettuce and soil under cadmium stress was investigated. The results showed that the application of straw increased the total nitrogen, total phosphorus and total potassium contents in shoot of lettuce, except for the content of total nitrogen in shoots of lettuce by applying the straw of S. photeinocarpum whose male parent was from Ya’an. The content of soil effective nutrients, the activity of urease, sucrase and catalase in soil increased remarkably after applied straw of S. photeinocarpum, especially the straw of S. photeinocarpum whose male parent was from Chengdu. It can be seen that during the process of maturity of S. photeinocarpum straw, a large amount of nutrients were released, the soil fertility and soil enzyme activity were improved, and the nutrient uptake of lettuce was promoted, too. Therefore, it was conducive to the growth of lettuce.

1. Introduction

Cadmium (Cd) is considered as the most important heavy metal of concern for soil and food chain contamination \[1\] because of its high mobility in the plant soil system \[2\]. Plants growing in Cd-contaminated soils can absorb and accumulate Cd in edible tissues, especially leafy vegetables \[3-4\]. Among vegetables, lettuce widely is cultivated worldwide and is popular because it is rich in minerals and vitamins, so its consumption may represent an effective risk for human health.

Soil nutrient contents directly affect the absorption of nutrients by plants. Reasonable application of straw can significantly increase the absorption of soil nutrients in crops under Cd stress conditions, because the straw decays and releases organic matter and other nutrients such as nitrogen, phosphorus, and potassium into the soil \[5\]. Previous studies have shown that returning a crop’s straw significantly increased the nitrogen, phosphorus, and potassium of soil \[6\]. In addition, the viability, growth potential, stress resistance, adaptability, yield, and quality of hybrids may show significantly higher than their parental.

Therefore, the straw of Solanum photeinocarpum and their hybrids were applied in this experiment. The nutrient of lettuce and soil were studied, and it could provide reference for safe vegetable crop production and heavy metal phytoremediation technology in areas with Cd-contaminated soil.
2. Materials and Methods

2.1. Materials
In November 2015, two ecotypes of *S. photeinocarpum* seeds were collected from the Ya'an Campus and Chengdu Campus of Sichuan Agricultural University. Ya'an Campus Farm (29°59'N, 102°59'E) is located in Yucheng District of Ya'an City. It belongs to the middle and subtropical-cold zone of the western Sichuan Basin. The Chengdu Campus (30°42'N, 103°51'E) is located in Wenjiang District Chengdu City. It belongs to the middle and subtropical spring and summer drought areas in the western Sichuan Basin. In April 2016, the seeds were sowed. The flower buds of two ecotypes of *S. photeinocarpum* were selected in flourishing florescence, and reciprocal hybridized. The hybrid seeds were collected when the fruit were matured.

In April 2017, the seeds of *S. photeinocarpum* and their hybrids were sowed in uncontaminated soil. The shoots of them were collected in full bearing period, and the fruit is removed. Dried at 75 °C to a constant weight, and then cut into small pieces of 1 cm, reserved.

The seeds of 'Glass lettuce' were purchased from Chengdu seed station. The soil were collected from the nearby farmland of Chengdu campus of Sichuan Agricultural University.

2.2. Experimental Design
The application of straw experiment was conducted at the Chengdu campus from August to December in 2017. In August, the soil samples were air-dried and passed through a 5 mm sieve. Then, 3.0 kg of air-dried soil was weighed and placed into each polyethylene pot (21 cm high, 25 cm diameter). Cd was added to the soil samples as CdCl$_2$·2.5H$_2$O at a dose of 10 mg/kg [7-8]. The soils were mixed immediately and again after 4 weeks. Then, the powdered straw of *S. photeinocarpum* and their hybrids were added to contaminated soil, and 6 g of straw were applied to each pot (2 g straw per kilogram soil). In September, lettuce seeds were germinated on perlite saturated with distilled water in incubator at 20 °C. Four uniform seedlings with four completely unfolded leaves were transplanted into each pot after 15 day of culture. The five experimental treatments applied in the experiment were as follow: the control (no straw applied), straw of *S. photeinocarpum* from Ya'an (A$_1$), straw of *S. photeinocarpum* from Chengdu (A$_2$), straw of *S. photeinocarpum* whose male parent was from Ya’an (A$_3$) and straw of *S. photeinocarpum* whose male parent was from Chengdu (A$_4$). There were three pots per treatment, and each treatment was replicated three times. The soil moisture was maintained at 80% of field capacity during the lettuce growth process. The nutrient of lettuce, soil available nutrient [9] and soil enzyme activities [10] were determined when the lettuce was harvested (50 days after transplanted).

2.3. Statistic analyses
Statistical analyses were performed using SPSS 20.0 statistical software (IBM, Chicago, IL, USA). Data were analyzed by one-way ANOVA with least significant difference (LSD) at a 5% confidence level.

3. Results

3.1. nutrient content of lettuce plants
As shown in Table 1, there was no significant difference in total nitrogen content of lettuce shoots between application of straw and control. Among them, the lowest total nitrogen content appeared in A$_1$, and it was significantly lower than A$_2$ and A$_4$. The order of total nitrogen content in lettuce roots was as follows: A$_2$ > A$_4$ > control > A$_1$ > A$_3$.

For the total phosphorus content of lettuce. Applying straw of *S. photeinocarpum* and their hybrids significantly increased the total phosphorus content in shoots of lettuce (Table 1). The total phosphorus content in shoots of lettuce was increased by 14.81% (P < 0.05), 14.12% (P < 0.05), 16.63%
(P < 0.05) and 23.23% (P < 0.05), respectively, compared with the control. In roots, applying straw of *S. photeinocarpum* whose male parent was from Chengdu (A₄) significantly increased the total phosphorus content, it increased by 14.19% (P < 0.05) compared with the control. There was no significant difference in total phosphorus content of roots between A₁, A₂, A₃ and control. The total potassium content was as shown in table 1. Applying straw of *S. photeinocarpum* and their hybrids increased the total potassium content of shoots and roots. The total potassium content were the greatest in shoots and roots of A₄, being 26.75% (P < 0.05) and 40.39% (P < 0.05) more than the control. The order of them were as follows: A₄ > A₂ > A₃ > A₁ > control.

Table 1 Effect of straw of *S. photeinocarpum* and their hybrids on the nutrient of lettuce

| Straw | Total nitrogen (g/kg) | Total phosphorus (g/kg) | Total potassium (g/kg) |
|-------|----------------------|-------------------------|-----------------------|
|       | Shoot | Root | Shoot | Root | Shoot | Root |
| Control | 9.36±0.33ab | 7.70±0.30b | 4.39±0.16b | 4.51±0.14b | 86.48±3.71b | 57.04±0.30c |
| A₁     | 9.66±0.13ab | 7.44±0.08bc | 5.04±0.29a  | 4.79±0.17b | 99.58±1.45ab | 66.88±2.58b |
| A₂     | 10.53±0.86a  | 8.45±0.14a  | 5.01±0.02a  | 4.84±0.14ab | 100.60±1.56a | 72.85±4.17ab |
| A₃     | 8.86±0.52b  | 7.11±0.14c  | 5.12±0.06a  | 4.51±0.10b | 100.10±7.50ab | 70.90±4.03b |
| A₄     | 10.50±0.01a  | 8.42±0.14a  | 5.41±0.19a  | 5.15±0.06a | 109.61±8.41a | 80.08±0.32a |

3.2. effective nutrient content of soil

As shown in Table 2, the available nitrogen content in A₁, A₂ and A₃ significantly increased by 8.17% (P < 0.05), 11.14% (P < 0.05) and 14.12% (P < 0.05), respectively, compared with the control. However, there was no significant difference between A₄ and control. The available phosphorus content of soil were significantly increased after applying straw of *S. photeinocarpum* and their hybrids (Table 2). The available phosphorus content of A₁, A₂, A₃ and A₄ increased by 33.97% (P < 0.05), 15.84% (P < 0.05), 26.21% (P < 0.05) and 23.97% (P < 0.05), respectively, compared with the control. There was no significant difference in the available potassium content between application of straw and control (Table 2). The order of the available potassium content were as follows: A₃ > A₂ > A₁ > A₄ > control.

Table 2 Effect of straw of *S. photeinocarpum* and their hybrids on the effective nutrient content of soil

| Straw | Available nitrogen (mg/kg) | Available phosphorus (mg/kg) | Available potassium (mg/kg) |
|-------|---------------------------|-----------------------------|-----------------------------|
| Control | 35.27±1.84b  | 91.19±1.30c   | 155.00±14.28a              |
| A₁     | 38.15±2.86a  | 122.17±10.27a | 152.50±3.81a               |
| A₂     | 39.20±2.02a  | 105.63±1.69b  | 167.20±15.70a              |
| A₃     | 40.25±3.27a  | 115.09±4.41ab | 174.35±5.59a               |
| A₄     | 37.80±1.49ab | 112.33±3.12ab | 158.45±2.76a               |

3.3. soil enzyme activities

Soil enzyme activities were closely related to soil nutrient supply. As can be seen from Table 3, applying straw of *S. photeinocarpum* and their hybrids increased the activities of sucrase, urease, catalase and alkaline phosphatase content in cadmium-contaminated soil except that A₁ decreased the alkaline phosphatase content. Compared with the control, the soil sucrase activity of A₁, A₂, A₃ and A₄ significantly increased by 47.07% (P < 0.05), 35.04% (P < 0.05), 44.50% (P < 0.05) and 26.76%, respectively. The same results were observed in soil urease activity and soil catalase activity, application of different straw all significantly increased the soil urease activity. The greatest of soil urease activity and soil catalase activity appeared in A₄, and they increased by 20.01% (P < 0.05) and 35.71% (P < 0.05), respectively, compared with the control. The different results were observed in soil...
alkaline phosphatase activity. Compared with the control, the A2, A3 and A4 significantly increased the soil alkaline phosphatase activity, but the A1 decreased the soil alkaline phosphatase activity.

Table 3 Effect of straw of Oryza sativa and Cichorium endivia on soil enzyme activities

| Straw          | Soil sucrase activity (mg/g) | Soil urease activity (mg/g) | Soil catalase activity (ml/g) | Soil alkaline phosphatase activity (mg/g) |
|----------------|-------------------------------|-----------------------------|-------------------------------|------------------------------------------|
| Control        | 13.64±1.20b                  | 14.29±0.15c                 | 0.28±0.01c                    | 10.79±0.54c                              |
| A1             | 20.06±1.00a                  | 15.83±0.26b                 | 0.33±0.01b                    | 10.03±0.67c                              |
| A2             | 18.42±1.85a                  | 15.72±0.19b                 | 0.35±0.01ab                   | 13.05±0.15b                              |
| A3             | 19.71±1.22a                  | 15.69±0.04b                 | 0.34±0.02b                    | 14.99±0.27a                              |
| A4             | 17.29±0.09a                  | 17.15±0.26a                 | 0.38±0.01a                    | 14.86±0.41a                              |

4. Conclusion
Under Cd stress conditions, applying straw of S. photeinocarpum and their hybrids had positive effects on nutrient of lettuce and soil. According to the above indicators, application straw of S. photeinocarpum increased the total nitrogen, total phosphorus and total potassium contents in shoot of lettuce. The contents of available nitrogen, available phosphorus and available potassium were improved by applying straw of S. photeinocarpum and their hybrids. At the same time, the activities of sucrose, urease, catalase and alkaline phosphatase in contaminated soil increased when the straw of S. photeinocarpum were applied. These dates indicated that a large amount of nutrients were released after during the process of maturity of S. photeinocarpum straw. The soil fertility and soil enzyme activity were improved, thereby promoting the absorption of nutrients by lettuce. Therefore, application of S. photeinocarpum straw was conducive to the growth of lettuce. In this study, applying straw of S. photeinocarpum whose male parent was from Chengdu was the optimal choice.

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