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# EFFECTS OF PERLITE, GRASS CHARCOAL AND VERMICULITE ON ROOT GROWTH OF ISATIS (*ISATIS TINCTORIA* L. WOAD) AND SOIL NUTRIENT MIGRATION

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*Keywords:* Perlite, Grass charcoal, Vermiculite, Soil Nutrients

**Abstract**

Effects of perlite, vermiculite, and grass charcoal on root growth of Isatis and soil nutrients migration were studied, and the plant growth indicators and some soil properties of upper (0~5cm) and lower layer (5~15cm) were analyzed. The experiment treatments were loess (CK), loess : perlite = 3 : 1(A), loess : grass charcoal = 3 : 1(B), loess : vermiculite = 3 : 1(C), loess: perlite: grass charcoal = 6 : 1 : 1(A1), loess: perlite: vermiculite = 6 : 1 : 1(B1), loess: grass charcoal: vermiculite = 6 : 1 : 1(C1). The results showed that soil pH of vermiculite-containing treatments in the upper layer and grass charcoal treatment in the lower layer decreased significantly. Before planting, the available potassium and phosphorus of the upper layer were significantly higher than those of the lower layer, and soil organic matter (SOM) was slightly higher than that of the lower layer. After planting, the decrease of available potassium in the upper layer was less than that of the lower layer, and the decrease of available phosphorus and increase of SOM in the upper layer were slightly higher than that of the lower layer. In sum, it is preferred to choose B (loess : grass charcoal = 3 : 1) and A1 (loess: perlite: grass charcoal = 6 : 1 : 1) to improve the soil nutrient and utilization efficiency.

## Introduction

The rapid development of industrialization and urbanization has led to continuous reduction of high-quality arable land resources. Improving the amount and quality of arable land have become the key to alleviating the contradiction between human and land. Environmental materials have the advantages of largest use function, the lowest environmental load, economy and abundant reserves, thus they have broad application in soil improvement and crop yield increase (Hu *et al.* 2014, Xu *et al.* 2014). Perlite and vermiculite have a developed pore structure (Li *et al.* 2017, Zhang *et al.* 2019b), which can improve the soil tillage structure and enrich the soil moisture and nutrients (Zeng *et al.* 2016). Grass charcoal is rich in organic matter (Li 2012, Zhang *et al.* 2019a). Therefore, study of the effects of three materials on soil nutrients and plant growth is of great significance to the soil quality improvement in poor soil area.

At present, different scientists have partially studied the properties and applications of the three environmental materials. Research by Li *et al* (2016) showed that the bulk density of grass charcoal was 11.11% higher than that of vermiculite and 275.00% higher than that of perlite. The water-holding capacity and the aerated pores in descending order are perlite > vermiculite > grass charcoal and the water-holding pores in descending order are vermiculite > grass charcoal > perlite. Generally, the water holding capacity and air permeability of the matrix can be improved

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by adding certain amount of perlite (He and Xiong 2019). The acid-base buffering capacity of the three materials is grass charcoal > vermiculite > perlite, so perlite can be appropriately added to adjust the soil pH. In terms of application, Rubin *et al.* (2013) and Li *et al.* (2016) showed that grass charcoal can effectively improve the plant nutritional status and increase the soil biological activity. Xu *et al.* (2014) studied the properties of vermiculite in terms of nutrient content, water absorption and retention, and anti-evaporation, and showed that vermiculite has the best water retention capacity compared to oil residue, weathered coal and shale. Fang *et al.* (2017) showed that perlite can improve the physical and mechanical structure of soil matrix. At present, there are few quantitative researches on the effects of these three materials on soil nutrient migration and Isatis root growth, and the combination ratio is inconsistent with the research. In the present study, different proportions of perlite, grass charcoal, vermiculite and loess were used for analyzing the growth of Isatis root and soil nutrients migration in upper (0~5 cm) and lower layer (5~15cm), to provide a scientific basis for the improvement of soil quality in poor soil areas.

## Materials and Methods

The pot experiment was carried out in the Greenhouse of Qinling Field Monitoring Center Station of Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd. The test soil was selected from this Center and the initial soil physical and chemical properties were as follows: pH was 8.0, conductivity was 0.40 μS/cm, available potassium was 275.6 mg/kg, available phosphorus was 175.0 mg/kg, total nitrogen was 0.96 g/kg, and soil organic matter was 11.55 g/kg. The test materials as perlite, vermiculite, and grass charcoal were purchased from Shaanxi Yangling Agricultural Supply and Marketing Station. The experimental pots were plastic with a diameter of 30 cm and a height of 50 cm. There were seven treatments and each with three replicates (Table 1), and a total of 21 pots with 5 kg of soil were used. Full and round Isatis seeds were selected for seedlings, and transplanted the better one in each pot according to the size and growth. Water and topdress were added to each pot regularly to ensure the same amount of water and fertilizer.

**Table 1. Experiment design.**

| Number | Treatments |
|---|---|
| CK | Loess |
| A | Loess : Perlite = 3 : 1 |
| B | Loess : Grass charcoal = 3 : 1 |
| C | Loess : Vermiculite = 3 : 1 |
| A1 | Loess : Perlite: grass charcoal = 6 : 1 : 1 |
| B1 | Loess : Perlite: vermiculite = 6 : 1 : 1 |
| C1 | Loess : Grass charcoal : Vermiculite = 6 : 1 : 1 |

During the harvest period, a ruler and an electronic balance were used to measure the plant height (cm), the fresh weight (g) of the above ground and below ground of the Isatis root. After harvest, the collected soil samples from the upper (0 ~ 5 cm) and lower layer (5 - 15 cm) were air-dried the animal and plant residues were removed and divided into three parts. One part was passed through a 2 mm sieve to determine the soil pH. The other part was passed through a 1 mm sieve to determine soil available potassium and available phosphorus, measured by a flame photometer and the ultraviolet spectrophotometer method. And another part was passed through a 0.149 mm sieve to determine the soil organic matter (SOM), measured by the potassium dichromate volumetric method. All data and drawing were classified and sorted by Excel 2010, SPSS 19.0 was used for analysis of variance and multiple comparisons.

**Results and Discussion**

The lowest and highest average plant heights were 66.0 cm for CK and 74.0 cm for B, secondly was 72.6 cm for A1 (Fig.1). There was no significant difference in plant height among the other treatments, indicating that the addition of grass charcoal can significantly promote the plant height growth of Isatis root.

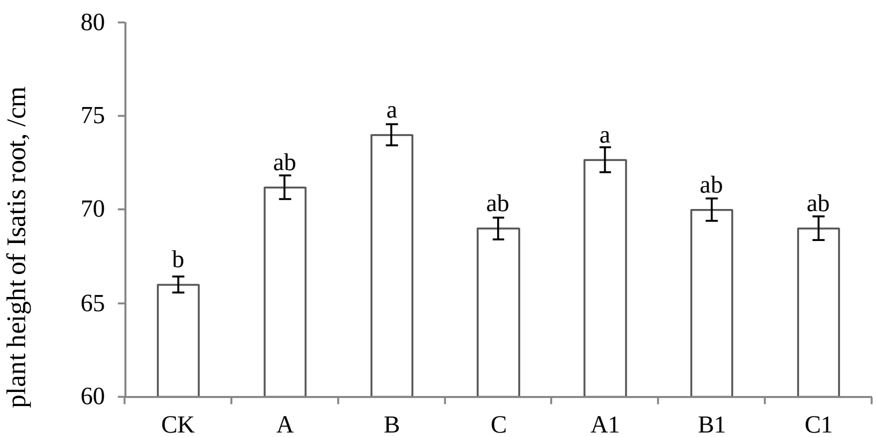


Fig. 1. Plant height of Isatis root in different treatments.

Compared with CK, the biomass of Isatis root increased after adding three materials (Fig.2). The biomass of Isatis root in B and A1 were 64.84 and 64.18 g, respectively. The highest above-ground biomass of B1 was 43.02 g, and the underground biomass of B, A and A1 were 25.08, 24.26 and 23.77 g, respectively in descending order. The root-shoot ratio of these three was also higher compared with CK.

The Isatis root grew better in perlite-containing groups than in the vermiculite-bearing groups, indicating that the synergistic effect of perlite and grass charcoal was better than vermiculite and grass charcoal. The Isatis root for B group grew best, which might be due to grass charcoal which is rich in organic matter with sufficient nutrients. The bulk density of perlite is smaller than that of vermiculite and its water holding capacity and air pores are better than vermiculite (Zhao *et al*. 2016), thus adding perlite to the soil is more conducive to the root respiration and extension for plant absorption. Therefore, it is more feasible to adding a certain amount of perlite in grass charcoal (Ma *et al*. 2017).

Compared with CK, after adding grass charcoal, vermiculite and perlite, the soil pH of the upper layer (0-5cm) and lower layer (5-15cm) both decreased. Before planting, the average pH of the upper soil was 7.85, the maximum was 8.07 for CK, and the minimum was 7.75 for C. After planting the average soil pH was 7.69, the maximum was 7.80 for CK, and the minimum was 7.58 for C1. The soil pH of upper layer before and after planting decreased by an average of 0.16 units, of which CK decreased by 0.27 units, followed by C1 by 0.22 units, indicating that the addition of vermiculite in the upper soil can significantly reduce the soil pH compared to the grass charcoal and perlite.

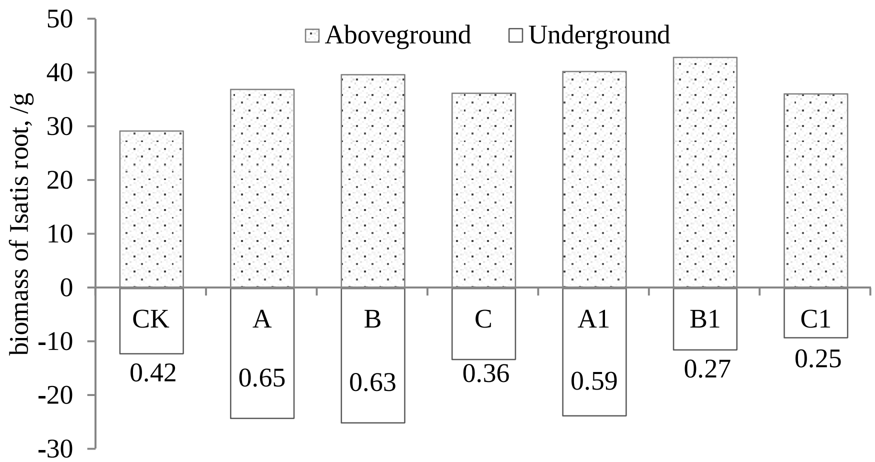


Fig. 2. Biomass of Isatis root in different treatments.

The average pH of the lower soil before planting was 7.77, the maximum for CK was 7.97, and the minimum for B was 7.67. After planting, the average soil pH was 7.72, the maximum for CK was 7.83, and the minimum for B was 7.65. Before and after planting, the pH of the lower soil decreased by an average of 0.06 units, of which CK decreased by 0.14 units, followed by A1 of 0.10 units. The soil pH of the lower layer for B decreased significantly, and pH of the upper soil was higher than that of the lower soil before and after planting.

Soil pH can affect the nutrients absorption of plants. Appropriate addition of different modified substrates can alleviate the damage to plants caused by fluctuations in soil pH (Zhang 2019). In the present study, the soil pH of both upper and lower layer decreased after adding the three materials to the weakly alkaline soil (Fig. 3). The soil pH of the upper layer in vermiculite-bearing group and the lower layer in grass charcoal-containing group decreased significantly before and after planting, while the addition of perlite has no significant effect on the soil pH. On one hand, it might be due to the acidity and alkalinity of the material itself, on the other hand, it probably related to the lowering of pH by root exudates during plant growth (Wang *et al.* 2019).

Fig. 4 showed that compared with CK, the available potassium of the upper (0-5cm) and lower (5-15cm) soil increased after adding 3 materials. The average available potassium in the upper soil before planting was 384.58 mg/kg, of which the minimum was 299.61 mg/kg for CK, and the maximum was 433.68 mg/kg for B1. After planting the average soil available potassium was 169.82 mg/kg, of which the maximum of B was 357.87 mg/kg, and the minimum of A was 122.40 mg/kg. The average decrease of available potassium in the upper soil before and after planting was 56.1%. The lowest value of B was 15.7%, the decrease of CK was 53.5%, and the decreases of other treatments were greater than 60%. Among them, A had the lowest value of 70.1%.

Before planting, the average available potassium in the lower soil was 330.69 mg/kg, the maximum was 375.56 mg/kg for C1, and the minimum was 251.25 mg/kg for CK. After planting the average soil available potassium was 127.82 mg/kg, the maximum value was 309.01 mg/kg for

B, and the minimum value was 88.7 mg/kg for CK. Before and after planting, the average decrease of available potassium in the lower layer was 61.2%. The minimum decrease of B was 8.8%, and the maximum decrease of C1 was 74.7%.

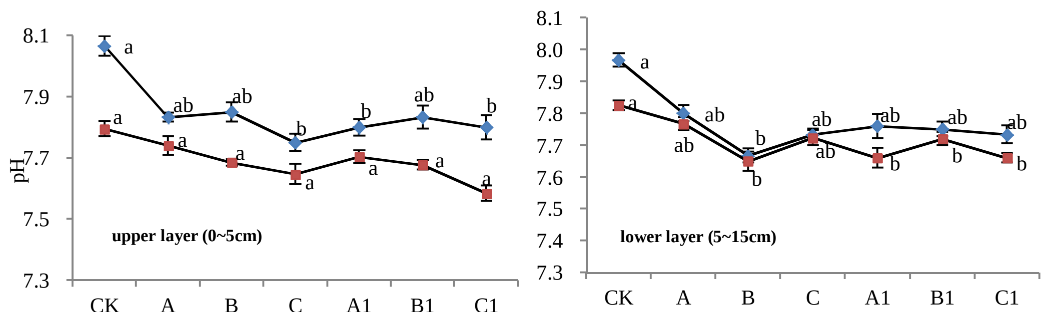


Fig. 3. Soil pH before and after planting in different treatments.
(The blue one: before planting, the red one: after planting).

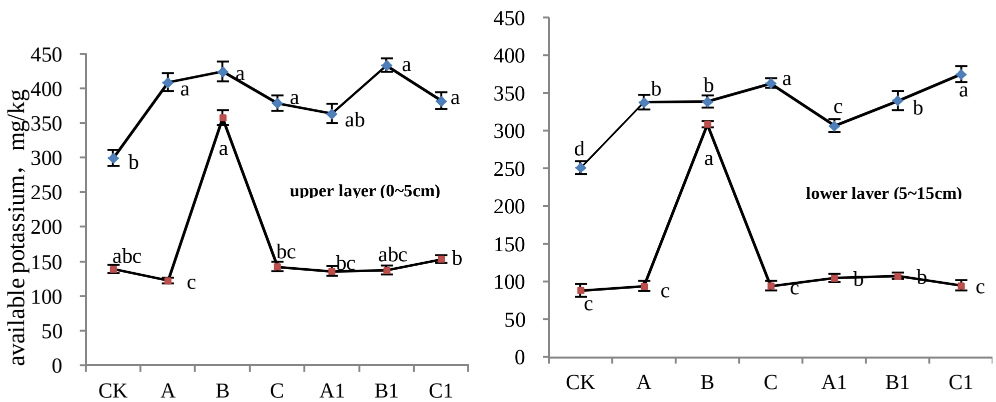


Fig. 4. The soil available potassium before and after planting in different treatments.
(The blue one: before planting, the red one: after planting)

Compared with CK, the available phosphorus in the upper layer before and after planting and the lower soil layer before planting increased after adding 3 kinds of materials, while the available phosphorus in the lower soil layer decreased slightly after planting (Fig.5). The average available phosphorus in the upper soil before planting was 233.50 mg/kg, the minimum value was 177.85 mg/kg for CK, and the maximum value was 283.35 mg/kg for A1. The average soil available phosphorus after planting was 106.12 mg/kg, the maximum value of B was 110.88 mg/kg, the second value was 110.48 mg/kg of A, and the minimum of CK was 99.12 mg/kg. The average decrease of available phosphorus in the upper soil before and after planting was 53.6%, the lowest was at CK treatment (44.3%).

The average available phosphorus before planting in the lower soil was 190.79 mg/kg, the maximum for A1 was 219.00 mg/kg, the next for C1 was 210.80 mg/kg, and the minimum for CK was 162.95 mg/kg. After planting the average soil available phosphorus was 118.59 mg/kg, the maximum value of B1 was 128.85 mg/kg, and the minimum value of A was 105.58 mg/kg. Before and after planting, the average decrease of available phosphorus in the lower soil was 37.3%, the lowest was at CK (22.5%).

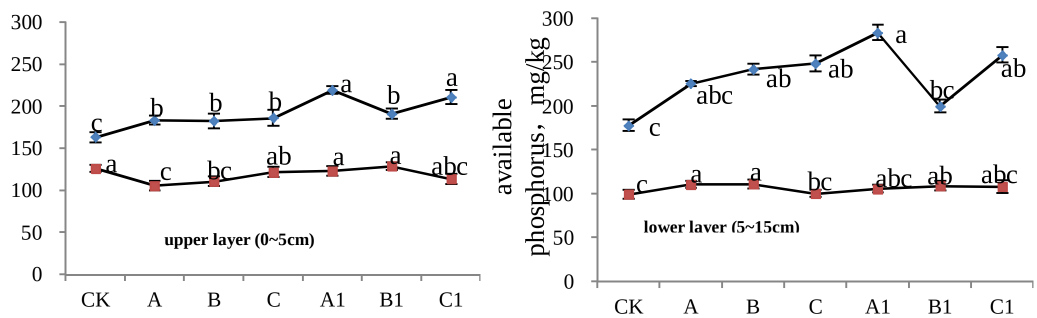


Fig. 5. The soil available phosphorus before and after planting in different treatments.
(the blue one: before planting, the red one: after planting)

The available phosphorus in the grass charcoal-bearing treatment increased more significantly, whereas in the other treatments the increase was not found significantly. Grass charcoal contributes to the promotion and preservation of soil available phosphorus, which is consistent with the result of Zhang (2019). The typical lamellar structure of vermiculite and honeycomb structure of perlite was more developed and the pores were looser. Both have good adsorption properties and can adsorb more phosphorus (Ma *et al*, 2017), so the mixed matrix has more phosphate fertilizer than a single matrix. Before and after planting, the soil available phosphorus of upper layer was found to be significantly higher than that of the lower, which may be related to man-made filling. While the decline of the upper soil was slightly greater than that of the lower. This might be due to the continuous infiltration of available phosphorus with water and nutrients absorption by plant roots (Kruse *et al.* 2015).

Different from the migration of available potassium and available phosphorus, the soil organic matter (SOM) in the upper (0-5 cm) and lower (5-15 cm) changes differently before and after planting after adding 3 materials (Fig. 6). The average SOM in the upper soil before planting was 13.17 g/kg, the maximum for C1 was 15.91 g/kg, followed by B was 15.47 g/kg, and the minimum for C was 9.92 g/kg. After planting the average SOM was 22.78 g/kg, the maximum for B was 46.23 g/kg, the minimum for A1 was 17.38 g/kg, and the other treatments had little difference from CK. Before and after planting the average increase in SOM in the upper soil was 35.7%, the minimum increase in C1 was 9.1%, the maximum increase in B was 66.55%, and the second was 56.57% in B1.

The average SOM in the lower soil before planting was 12.91 g/kg, the maximum for B was 23.37 g/kg, the next for C1 was 14.45 g/kg, and the minimum for CK was 9.17 g/kg. After planting, the average SOM was 20.66 g/kg, the maximum value of B was 45.29 g/kg, and the minimum value of C was 12.83 g/kg. Before and after planting, the average increase in SOM in the lower soil was 33.5%, with the lowest increase of C1 (7.5%), followed by A1 (19.68%), and the remaining treatments were greater than 25%, with the highest increase of B1 (57.77%).

Soil organic matter increases significantly when grass charcoal was added to the soil, because it is rich in organic matter. Perlite and vermiculite have less organic matter, mainly promoting the SOM indirectly by improving the soil structure (Sun 2019). Therefore, the addition of vermiculite, perlite and their mixture alone has no significant effect on the SOM improvement. In general, the higher SOM in the upper layer before planting may be related to artificial filling (Meric *et al*, 2011). SOM increased after planting and the increase in the upper layer was slightly higher than that in the lower layer. This might be related to the fact that the upper layer has more litter and the root system absorbs more nutrients in the lower layer.

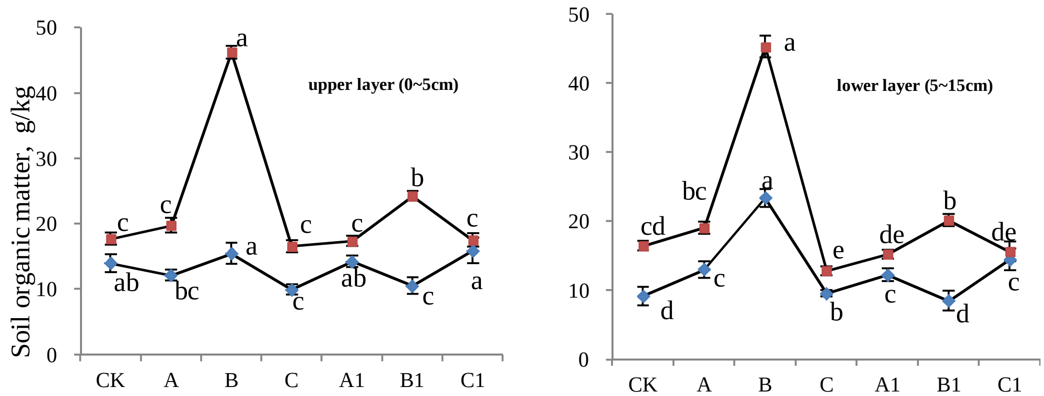


Fig. 6. The soil organic matter before and after planting in different treatments.
(The blue one: before planting, the red one: after planting)

The present study showed that the addition of three materials can effectively promote the Isatis root growth, and the addition of grass charcoal alone is most conducive. For the limited resources and high cost of grass charcoal, a certain amount of perlite can be added together to promote the growth of Isatis root. The pH of the upper soil in the treatment containing vermiculite decreased significantly before and after planting, and the pH of the lower soil in the treatment containing grass charcoal decreased significantly. The addition of perlite had no significant effect on the pH of the upper and lower soil.

Soil available potassium and phosphorus increased before planting, and potassium increased more significantly in the treatments with grass charcoal and vermiculite alone. The soil available phosphorus of grass charcoal-bearing treatment increased significantly and the SOM of grass charcoal-alone improved more. Overall, adding grass charcoal alone is most conducive to the retention of soil nutrients. In terms of different soil layers, the available potassium and phosphorus of the upper layer are significantly higher than those of the lower layer, and SOM was slightly higher in upper layer than that of the lower layer. After planting, the decrease of available potassium in the upper layer was less than that of the lower layer, and the decrease of available phosphorus and increase of SOM in the upper layer are slightly higher than that of the lower layer. In summary, the treatments of B (loess: grass charcoal = 3 : 1) and A1 (loess: perlite: grass charcoal = 6 : 1 : 1) may be recommended to improve the soil nutrient and utilization efficiency.

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