Applying Hyperaccumulator Straw in Cd-Contaminated Soil Enhances Nutrient Uptake and Soil Enzyme Activity of *Capsella bursa-pastoris*

Jin Wang[1,a], Keng Wen[1,b], Jun Shi[2,c] and Xiulan Lv[3,d]*

[1]College of Horticulture, Sichuan Agricultural University, Chengdu, Sichuan, China

[2]Mianyang Academy of Agricultural Sciences, Mianyang, Sichuan, China

[3]Institute of Pomology and Olericulture, Sichuan Agricultural University, Chengdu, Sichuan, China

[a]wangjin2510@126.com, [b]529112874@qq.com, [c]tibm@163.com, [d]xllvjj@163.com

*Corresponding author

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Abstract. The effects of applying four hyperaccumulator species (*Solanum photeinocarpum, Bidens pilosa, Siegesbeckia orientalis* and *Youngia erythrocarpa*) straws in cadmium (Cd) contaminated soil on phosphorus (P) and potassium (K) uptake and soil enzyme activity of *Capsella bursa-pastoris* were studied through a pot experiment. Five treatments were used in the experiment: control (no straw applied), and straw applied for each of the four hyperaccumulator species (*S. photeinocarpum* , *B. pilosa*, *S. orientalis* and *Y. erythrocarpa*). When applying the four hyperaccumulator species straws, the total P and K contents in roots, stems and leaves of *C. bursa-pastoris* increased compared with control. The total P and K contents in roots, stems and leaves of *C. bursa-pastoris* were ranked as: *S. photeinocarpum* straw > *Y. erythrocarpa* straw > *B. pilosa* straw > *S. orientalis* straw > control. The soil available P and K contents were also increased by the four hyperaccumulator species straws. The four hyperaccumulator species straws enhanced soil sucrase, soil catalase and soil urease activities. Therefore, applying hyperaccumulator straw could used to increase nutrient content and enhance soil enzyme activity of *C. bursa-pastoris* in Cd-contaminated soil, and the straw of *S. photeinocarpum* was the best.

Introduction

Applying straw into soil is a commonly used measure of agricultural production [1]. After applying straw, significant amount of carbon, nitrogen, phosphorus, potassium and other nutrients are released by soil microbial action, and thus improve soil fertility [2]. Meanwhile, the straw also improves the soil enzyme activity, the number of micro-organisms and the effectiveness of soil nutrients, and thereby improves soil physical and chemical properties [3]. These results indicate that applying the plant straw into soil can change the biological effectiveness of various elements, and affect the nutrient elements absorption of plant.

The summer growth cadmium (Cd) hyperaccumulator plants *Youngia erythrocarpa* [4], *Bidens pilosa* [5], *Solanum photeinocarpum* [6] and *Siegesbeckia orientalis* [7] have strong tolerance to Cd. In this study, we applied the straw made from the shoots of *Y. erythrocarpa, B. pilosa, S. photeinocarpum* and *S. orientalis* into Cd-contaminated soil and planted the winter growth Cd-accumulator plant *Capsella bursa-pastoris* [8]. The aim of the study was to determine if application of straw from the hyperaccumulator species could efficiently promote the phosphorus (P) and potassium (K) uptake and soil enzyme activity of *C. bursa-pastoris,* and improve the phytoremediation ability of *C. bursa-pastoris.*

Materials and Methods

Materials. In August 2013, the shoots of *S. photeinocarpum* , *B. pilosa, S. orientalis* and *Y. erythrocarpa* were collected from the Ya'an campus farm of the Sichuan Agricultural University

(29°59′N, 102°59′E), China, from uncontaminated soil areas. The collected shoots of these plants were dried at 80 °C to constant weight, finely ground and sieved through a 5-mm-mesh nylon sieve. *Capsella bursa-pastoris* seedlings with two euphyllas were collected from the Ya'an campus farm (from uncontaminated soil) in September 2013. The inceptisol soil samples were collected from Ya'an campus farm in August 2013. The basic properties of the soil were the same as reference [4].

Experimental Design. The experiment was conducted at the Ya'an campus farm from August to October in 2013. The soil samples were air-dried and passed through a 5-mm sieve. Three kilograms of the air-dried soil was weighed into each polyethylene pot (15 cm high, 18 cm in diameter). Cd was added to soils as $CdCl_2 \cdot 2.5H_2O$ at 50 mg/kg. The pots were soaked in the Cd solutions for 4 weeks, and then the soil in each pot was mixed with the powdered shoots of the studied plants. Six-gram shoots were applied to each pot (2 g shoots per kg soil), and the soil moisture was maintained at 80% of field capacity for 1 week. The five experimental treatments in the experiment were control (no straw applied), applying *S. photeinocarpum* straw, applying *B. pilosa* straw, applying *S. orientalis* straw and applying *Y. erythrocarpa* straw. Each treatment was replicated three times using a completely randomized design with 10-cm spacing between pots. Four uniform seedlings of *C. bursa-pastoris* were transplanted into each pot and the soil moisture content was maintained at 80% of field capacity from the time the plants were transplanted into the pots until the time the plants were harvested. At maturity (after 35 d), the entire plants were harvested for determining contents of total P and K in roots and shoots [9]. The soil samples were collected for determining soil available P and K contents [9] and soil enzyme activity [10].

Results and Discussion

Total P content in *C. bursa-pastoris*. Applying hyperaccumulator straw in Cd-contaminated soil increased total P contents in roots, stems and leaves of *C. bursa-pastoris* compared with control (Table 1). The total P contents in roots, stems and leaves of *C. bursa-pastoris* were ranked as: *S. photeinocarpum* straw > *Y. erythrocarpa* straw > *B. pilosa* straw > *S. orientalis* straw > control. Applying straws of *S. photeinocarpum*, *B. pilosa*, *S. orientalis* and *Y. erythrocarpa* in Cd-contaminated soil increased the total P content in roots of *C. bursa-pastoris* by 47.51% ($p < 0.05$), 9.09% ($p > 0.05$), 4.40% ($p > 0.05$) and 22.29% ($p < 0.05$) respectively compared with control, total P content in stems increased by 19.31% ($p < 0.05$), 11.53% ($p > 0.05$), 9.66% ($p > 0.05$) and 12.15% ($p > 0.05$) respectively, and total P content in leaves increased by 45.87% ($p < 0.05$), 31.02% ($p < 0.05$), 18.81% ($p < 0.05$) and 37.95% ($p < 0.05$) in leaves respectively.

Table 1 Total P content in *C. bursa-pastoris*

Treatments	Roots (g/kg)	Stems (g/kg)	Leaves (g/kg)
Control	3.41±0.16c	3.21±0.09b	3.03±0.30d
S. photeinocarpum	5.03±0.13a	3.83±0.11a	4.42±0.08a
B. pilosa	3.72±0.24bc	3.58±0.30ab	3.97±0.10bc
S. orientalis	3.56±0.19c	3.52±0.10ab	3.60±0.13c
Y. erythrocarpa	4.17±0.26b	3.60±0.14ab	4.18±0.11ab

Values are means of three replicate pots. Different lowercase letters indicate significant differences based on one-way analysis of variance in SPSS 13.0 followed by the least significant difference test ($p < 0.05$).

Total K content in *C. bursa-pastoris*. When applying hyperaccumulator straw in Cd-contaminated soil, the total K contents in roots, stems and leaves of *C. bursa-pastoris* increased (Table 2). The total K contents in roots, stems and leaves of *C. bursa-pastoris* were ranked as: *S. photeinocarpum* straw > *Y. erythrocarpa* straw > *B. pilosa* straw > *S. orientalis* straw > control, which was the same as total P content in *C. bursa-pastoris*. Applying straws of *S. photeinocarpum*, *B. pilosa*, *S. orientalis* and *Y. erythrocarpa* in Cd-contaminated soil increased the total K content in roots of *C. bursa-pastoris* by

15.07% ($p < 0.05$), 6.71% ($p > 0.05$), 2.88% ($p > 0.05$) and 12.88% ($p < 0.05$) respectively compared with control, total K content in stems increased by 31.23% ($p < 0.05$), 22.41% ($p < 0.05$), 5.17% ($p > 0.05$) and 26.05% ($p < 0.05$) respectively, and total K content in leaves increased by 15.44% ($p < 0.05$), 8.08% ($p < 0.05$), 6.63% ($p > 0.05$) and 9.53% ($p < 0.05$) in leaves respectively.

Table 2 Total K content in *C. bursa-pastoris*

Treatments	Roots (g/kg)	Stems (g/kg)	Leaves (g/kg)
Control	7.30±0.14b	5.22±0.13b	8.29±0.31c
S. photeinocarpum	8.40±0.28a	6.85±0.08a	9.57±0.34a
B. pilosa	7.79±0.30ab	6.39±0.17a	8.96±0.23ab
S. orientalis	7.51±0.23b	5.49±0.14b	8.84±0.18bc
Y. erythrocarpa	8.24±0.37a	6.58±0.35a	9.08±0.11ab

Values are means of three replicate pots. Different lowercase letters indicate significant differences based on one-way analysis of variance in SPSS 13.0 followed by the least significant difference test ($p < 0.05$).

Soil available P content. Compared with control, when applying the four hyperaccumulator species straws in Cd-contaminated soil, the soil available P content increased (Fig. 1). The soil available P content was ranked as: *S. photeinocarpum* straw > *Y. erythrocarpa* straw > *B. pilosa* straw > *S. orientalis* straw > control.

Soil available K content. The soil available K content increased compared with control when applying the four hyperaccumulator species straws in Cd-contaminated soil (Fig. 2). The soil available K content was also ranked as: *S. photeinocarpum* straw > *Y. erythrocarpa* straw > *B. pilosa* straw > *S. orientalis* straw > control. Compared with control, the soil available K content of applying straws of *S. photeinocarpum*, *B. pilosa*, *S. orientalis* and *Y. erythrocarpa* increased by 7.00% ($p < 0.05$), 2.26% ($p > 0.05$), 0.78% ($p > 0.05$) and 5.84% ($p < 0.05$) respectively.

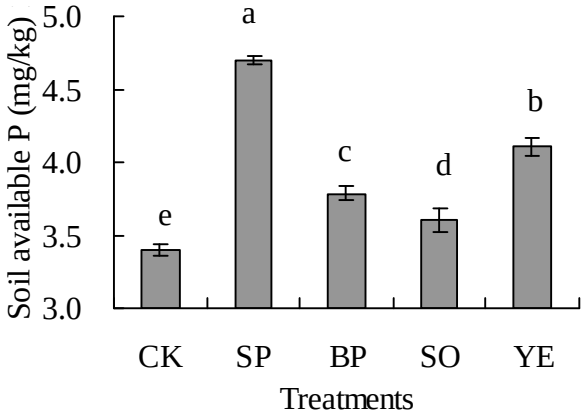

Fig. 1 Soil available K. Values are means of three replicate pots. Different lowercase letters indicate significant differences based on one-way analysis of variance in SPSS 13.0 followed by the least significant difference test ($p < 0.05$). CK = control, SP = *S. photeinocarpum*, BP = *B. pilosa*, SO = *S. orientalis*, YE = *Y. erythrocarpa*.

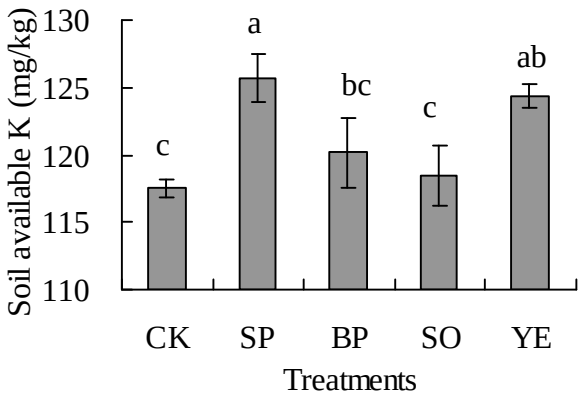

Fig. 2 Soil available K. Values are means of three replicate pots. Different lowercase letters indicate significant differences based on one-way analysis of variance in SPSS 13.0 followed by the least significant difference test ($p < 0.05$). CK = control, SP = *S. photeinocarpum*, BP = *B. pilosa*, SO = *S. orientalis*, YE = *Y. erythrocarpa*.

Soil enzyme activity. The four hyperaccumulator species straws enhanced soil sucrase, soil catalase and soil urease activities of Cd-contaminated soil (Table 3). The soil sucrase activity was ranked as: *S. photeinocarpum* straw > *B. pilosa* straw > *Y. erythrocarpa* straw > *S. orientalis* straw > control, soil urease activity was ranked as: *S. photeinocarpum* straw > *B. pilosa* straw > *S. orientalis* straw > *Y. erythrocarpa* straw > control, and soil catalase activity was ranked as: *Y. erythrocarpa* straw > *S. orientalis* straw > *S. photeinocarpum* straw > *B. pilosa* straw > control.

Table 3 Soil enzyme activity

Treatments	Soil sucrase activity (mg/g)	Soil urease activity (mg/g)	Soil catalase activity (ml/g)
Control	0.474±0.006d	0.398±0.013e	0.262±0.025c
S. photeinocarpum	0.776±0.009a	1.605±0.036a	0.304±0.005b
B. pilosa	0.735±0.005a	1.451±0.033b	0.274±0.011bc
S. orientalis	0.531±0.033c	0.958±0.020c	0.348±0.007a
Y. erythrocarpa	0.624±0.024b	0.595±0.034d	0.379±0.016a

Values are means of three replicate pots. Different lowercase letters indicate significant differences based on one-way analysis of variance in SPSS 13.0 followed by the least significant difference test ($p < 0.05$).

Conclusions

When applying the four hyperaccumulator species (*S. photeinocarpum*, *B. pilosa*, *S. orientalis* and *Y. erythrocarpa*) straws in Cd-contaminated soil, the total P and K contents in roots, stems and leaves of *C. bursa-pastoris* increased compared with control. The soil available P and K contents were also increased by the four hyperaccumulator species straws. The four hyperaccumulator species straws enhanced soil sucrase, soil catalase and soil urease activities. Therefore, applying hyperaccumulator straw could used to increase nutrient content and enhance soil enzyme activity of *C. bursa-pastoris* in Cd-contaminated soil, and the *S. photeinocarpum* straw was the best.

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