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Effects of Mixed Cropping of Garden Plants with *Brassica parachinensis* on Remediation of Cr-Polluted Soil in Community Garden

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Abstract: Industrialization and urbanization have produced large amounts of atmospheric and soil pollutants. Among them, heavy metals are one of the main byproducts that are widely distributed in the atmosphere, water, soil and organisms, which have a great impact on climate. It is of great significance to reduce their enrichment in soil by ecological restoration methods for the sustainable development of urban atmosphere and climate. This study investigated the effects of different garden plants (*Festuca arundinacea*, *Ageratum conyzoides*, *Trifolium repens*) mixed with *Brassica parachinensis* on plant growth, physiological indexes and Cr (chromium) content in aboveground and underground parts in Cr (the main heavy metal pollution produced by industrialization) contaminated soil. The yield of *B. parachinensis* was the highest under the mixed cropping mode with *T. repens*, with the Cr content in edible parts being lower than the standard, suggesting an effective combination of *B. parachinensis* in community gardens. The mixed cropping of *F. arundinacea* with Bra decreased *B. parachinensis* yield. Under the mixed cropping of *A. conyzoides*, the edible parts of *B. parachinensis* were aggravated by Cr pollution, which was not recommended for planting. Our results suggest that converting the monoculture mode of vegetables to mixed cropping with garden plants reduced heavy metal pollution of community garden plants and improved soil productivity and environmental quality.

Keywords: climatic change; atmospheric pollution; Cr; community gardens; phytoremediation; heavy metal

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1. Introduction

The community garden is a new type of green space form that serves the community residents and has both agricultural productivity and landscape appreciation [1]. It has multiple functions and is called a community farm in some countries [2]. Planting can enhance residents' sensitivity to climate change and cultivate the ability of community horticultural planting groups to prevent climate risks in a timely manner. Increased community participation alongside planting activities can familiarize residents with the environmental issues facing global climate change. Community gardens are usually transformed from idle green space, wasteland, brownfields or roof space inside and around the house [3]. The application of a plant mixed cropping system to community gardens is conducive to the safe and effective use of idle green space and brown land in the city, which is conducive to the construction of a safe urban ecological environment. At the same time, it can provide residents with healthy and edible vegetables nearby [4], so that residents can participate in the maintenance and management of vegetables, which is conducive to the popularization of climate change knowledge and the improvement of prevention awareness.

In the past, the development of urbanization has led to industrial pollution of many urban soils [5]; for example, excessive Cr in the soil has led to wilting of crop leaves and a serious decline in vegetable yields. Excessive accumulation of Cr in vegetables can cause strong toxic effects on human health [6] and even carcinogenic effects [7]. Excessive heavy metals in the soil will also enter the atmosphere through volatilization and release, causing damage to the community garden microclimate. Studies have pointed out that heavy metal pollution, novel coronavirus pneumonia and waste are harmful to the environment, and it is necessary to establish pollution detection and management strategies related to environmental changes and people's health [8]. Plants as natural detectors have potential value in this regard. *B. parachinensis* is an important green leafy vegetable indispensable in the daily diet [9], but it has strong absorption of heavy metals [10]. Phytoremediation is an economical and feasible method for the remediation of soil heavy metal pollution [11]. Monoculture to intercropping with economic crops can reduce the absorption of heavy metals by crops. This method achieves the purpose of repairing while reducing the enrichment of heavy metals by garden plants [12]. At present, the landscape plants in the community garden mainly bear the functions of ornamentation and health care and lack research on the remediation function of soil heavy metal pollution [13]. Selecting the appropriate mixed cropping plant combination can not only enrich the community structure of the landscape but also improve the urban soil Cr pollution caused by industrialization in the past. A few Cr hyperaccumulators have been found, such as *Leersia hexandra* Swartz [14], *Dicoma niccolifera Wild* and *Sutera fodina Wil* [15]. Some studies pointed out that *Pennisetum alopecuroides* and *A. conyzoides* [16] have a certain tolerance to Cr. Other studies found that *T. repens* [17] and *F. arundinacea* [18] have potential application value in Cr-contaminated soil treatment. *T. repens*, *F. arundinacea* and *A. conyzoides* can not only be used as ornamental plants in community garden landscapes with high economic benefits and fast growth but can also repair soil Cr pollution to prevent its accumulation in the soil from exceeding the standard into the atmosphere.

Therefore, in this study, the mixed planting method of Cr-tolerant garden plants and edible plants was applied to the construction of a community garden landscape, and the plant combinations that were beneficial to the safe production of vegetables and the remediation of soil pollution were explored. Three Cr-tolerant garden plants of different ornamental types, *F. arundinacea*, *A. conyzoides*, *T. repens* and *B. parachinensis*, were used for pot experiments in Cr-contaminated soil. The growth, physiological indexes, Cr content in edible parts and soil remediation effects of mixed and monoculture were analyzed. In this paper, the mixed cropping methods conducive to the edible safety of *B. parachinensis* were screened out, and the remediation effects of the three plants on Cr-contaminated soil were analyzed, which provided planting ideas for the application of *B. parachinensis* in community garden landscapes and the introduction of remediation garden plants to alleviate soil Cr pollution and provided reference for creating a safe and healthy microclimate environment and building a repairable urban public space landscape to alleviate climate change.

2. Materials and Methods

2.1. Test Soil

The test soil was collected from a city in the north-central part of Zhejiang Province. The climate in this area belongs to subtropical monsoon climate. The annual average temperature is 16 °C, the annual average precipitation is 1438 mm, and the annual sunshine hours are about 1969 h. The soil samples were taken from the pollution point (through the early soil sampling survey, it was found that the soil Cr content is very high, more than the national standard to reach the pollution level) as the pot test soil. The test soil type was red soil, and the heavy metal Cr content was 200 mg·kg^{-1}. Compared with the *Soil Geochemical Background Value of Zhejiang Province* [19] (Cr Background Value 77.5 mg·kg^{-1}), the Cr content of the test soil exceeded the standard by about 2 times, exceeding the *Soil Environmental Quality Standard Agricultural Land Soil Pollution Risk Screening Value (Trial)* (GB15618-2018) [20] (5 < pH < 7.5, soil Cr screening value 150 mg·kg^{-1}). Five soil cores with a depth of 0–20 cm were sampled and mixed. The soil was naturally air-dried and ground. Part of the soil was passed through a 2 mm sieve for the determination of basic physical and chemical indicators such as soil pH, available phosphorus, available potassium and alkali-hydrolyzable nitrogen. Part of the soil was passed through a 0.15 mm sieve for the determination of soil Cr total and available content. Soil physical and chemical properties and heavy metal content were determined according to the method of soil agrochemical analysis [21]. The results are shown in Table 1.

Table 1. Basic physical and chemical properties of tested soil.

Soil Type	Cr (mg·kg^{-1})	AN/(mg·kg^{-1})	AP/(mg·kg^{-1})	AK/(mg·kg^{-1})	pH	OM/(g·kg^{-1})	SBD/ (g·cm^{-3})
Red loam	200	221	96	35.22	6.00	4.16	1.39

Note: AN: alkaline nydrolysis nitrogen; AP: available phosphorus; AK: rapidly available potassium; OM: organic matter; SBD: soil bulk density.

2.2. Test Plants

The seeds of *B. parachinensis* were provided by Jieyang Nongyou Seed Company. The variety was No. 31 *Bra*. Firstly, the seeds were soaked for 6 h, then washed several times with deionized water, and the seedlings were raised in the seedling tray. The temperature was kept above 22 °C. After the seedlings grew two true leaves (true plant leaves are generally composed of stipules, petioles and leaves; generally, after growing two cotyledons, from the third leaf, it can be called a true leaf), the seedlings with similar size and growth were selected and transplanted into pots. The seeds of ornamental garden plants *F. arundinacea*, *A. conyzoides* and *T. repens* were purchased from the seed industry of Suqian Huaxiang Township, Jiangsu Province. The germination and seedling raising (no Cr pollution) were carried out in the greenhouse of Pingshan Practice Base of Zhejiang Agriculture and Forestry University.

2.3. Pot Experiments

The pot experiment was carried out in the greenhouse of Pingshan Practice Base of Zhejiang Agriculture and Forestry University in September 2021. After removing the debris, the tested soil was naturally air-dried, ground, passed through a 5 mm nylon sieve and mixed, and round white PVC pots (diameter 29.5 cm, height 19.7 cm) were used. Pots were filled with the tested Cr-contaminated soil, with 5 kg of soil per pot, the base fertilizer was applied for 15 days, and the experimental plant seedlings were simultaneously moved into the pots. There were 7 treatments, with each treatment replicated 3 times, and a total of 21 pots (see Table 2 for specific design). Pots had a space of 10 cm between each other, with a completely random arrangement. During incubation, irregular replacement of pot and pot position was performed to reduce the marginal effect. Monoculture vegetables 5 plants per pot, monoculture ornamental plants 5 plants per pot, mixed cropping vegetables 1 plant and ornamental plants 4 plants. Among them, one vegetable was planted in the center of the basin, and four ornamental plants were planted 10 cm away from the vegetables to maintain equal spacing distribution. The plants were cultured at 25 ± 2 °C (day) and 16 ± 2 °C (night), respectively, and regularly maintained and fertilized. During the growth period, the plants were watered with ultrapure water every 1–2 days and maintained at 70 % of the field capacity. *B. parachinensis*, *F. arundinacea*, *A. conyzoides* and *T. repens* have the same growth period from 1 September 2021 to 10 November 2021.

Table 2. Pot experiment design.

Soil	Planting Pattern	Treatment	Treatment Code
Cr-contaminated soil	Monoculture Mixed cropping	*B. parachinensisT. repensF. arundinacea* *A. conyzoidesB. parachinensis-F. arundinacea* *B. parachinensis-A. conyzoides* *B. parachinensis-T. repens*	T B G J TG TJ TB

2.4. Sample Collection

When harvesting, the plant was dug out with a plastic shovel near the root system of the plant, and the plant was taken back to the laboratory immediately after harvesting. After washing with water, the heavy metals attached to the surface were washed with deionized water to remove the heavy metals attached to the surface and then stored in a refrigerator at 4 °C for the determination of plant enzyme activity. The remaining plant samples were divided into two parts: aboveground and underground. They were under high-temperature decolorization in the oven at 105 °C for 30 min, then dried to constant weight at 80 °C, crushed and stored in plastic bags for the determination of heavy metal Cr content in plants. Root soil was collected by shaking root method, and non-rhizosphere soil was collected by quartering method. Soil from each pot was randomly taken at 4 points with a plastic shovel to form a mixed soil sample. All soil samples were divided into two parts after natural air drying and grinding. One part was used to determine soil pH by 2 mm sieve, and the other part was used to determine the total amount and available content of Cr by 0.15 mm sieve.

2.5. Indicator Determination

2.5.1. Soil Sample Analysis Method

Soil pH was extracted by CO_2-free distilled water (mwater: msoil = 2.5: 1) composite electrode method. The content of Cr was based on Determination of copper, zinc, lead, nickel and chromium in Soil and Sediment by Flame Atomic Absorption Spectrophotometry (HJ 491-2019) [22], and the effective state of heavy metals was extracted by dilute acid method and determined by atomic absorption spectrophotometer (Shimadzu, Japan, AA-7000) [23].

2.5.2. Plant Physiological Indexes and Cr Content Determination

Chlorophyll: The SPAD value of each treatment plant leaf was measured by chlorophyll meter (SPAD-502 Plus). The plant biomass was measured by 1% balance, and the plant height and root length were measured by 1 m tape. The content of malondialdehyde in plants was determined by thiobarbituric acid colorimetric method, the content of catalase was determined by ultraviolet spectrophotometry, and the content of Cr in plants was determined by EPA-3051 method recommended by the United States Environmental Protection Agency.

2.6. Statistical Analysis

Microsoft Excel 2018 software was used for data collation, and IBM SPSS Statistics 23 software was used for statistical analysis. One-way analysis of variance (one-way ANOVA) was used to test the significance of the data, and Duncan method was used to make multiple comparisons of the experimental data. The significance level of the difference was $p < 0.05$. The chart production of relevant data was completed by Origin 2021, and the experimental data were expressed as mean ± standard deviation (SD).

Transfer coefficient (TF) can reflect the ability of plants to transfer heavy metals from underground to aboveground parts [24] and was calculated as follows: Transfer coefficient (TF) = heavy metal content in aboveground parts / heavy metal content in roots. Enrichment coefficient (BCF) can reflect the capacity of plants to absorb heavy metals in planting system [25]: enrichment factor (BCF) = heavy metal content in a part of plant/heavy metal content in soil.

Plant aboveground/belowground Cr accumulation = Plant aboveground/belowground Cr content × Plant aboveground/belowground biomass;

Cr Removal Rate (remediation rate) = (soil Cr content before planting − Soil Cr Content after harvest)/Soil Cr Content before planting.

3. Results and Analysis

3.1. Effects of Different Mixed Cropping on Growth Characteristics of B. Parachinensis

The growth indexes of *B. parachinensis* under different mixed treatments are shown in Table 3. TB treatment significantly increased the aboveground and underground biomass, plant height and root length of *B. parachinensis* ($p < 0.05$), which had the maximum values in all treatments. Compared with monoculture, *T. repens* significantly increased the total biomass of *B. parachinensis* by 48.85%, the biomass of edible parts by 59.09%, the plant height by 64.60% and the root length by 43.09%. The aboveground and underground biomass of *B. parachinensis* in the TG treatment were significantly reduced by 49.50% and 48.71%, respectively, and the plant height and root length were significantly reduced by 42.35% and 41.75%, respectively. TJ treatment significantly increased the biomass of edible parts of *B. parachinensis*, and the total biomass and root length per plant did not change significantly.

Table 3. Basic physical and chemical properties of tested soil.

Plant Name	Treatment Number	Individual Biomass/g	Aerial Biomass/g	Ground Biomass/g	Plant Height/cm	Root Length/cm
B. parachinensis	TB	6.19 ± 0.20a	4.33 ± 0.11a	1.86 ± 0.15a	26.41 ± 0.68a	8.18 ± 0.45a
	TG	2.11 ± 0.04c	1.37 ± 0.05d	0.74 ± 0.01c	9.25 ± 0.72d	3.22 ± 0.17c
	TJ	4.55 ± 0.34b	3.11 ± 0.33b	1.44 ± 0.05b	18.00 ± 0.83b	5.71 ± 0.35b
	T	4.16 ± 0.15b	2.72 ± 0.07c	1.44 ± 0.13b	16.04 ± 0.55c	5.53 ± 0.33b

Note: different letters in the same column in the table indicate that the difference between different treatments is significant ($p < 0.05$). The data in the table are the mean ± standard deviation of 3 repetitions.

As shown in Table 4, the total biomass per plant of the three garden plants ranked as *T. repens* > *F. arundinacea* > *A. conyzoides.* Compared with monoculture, mixed cropping significantly increased the belowground biomass of *T. repens.* The total biomass of a single plant and aboveground biomass of *F. arundinacea* significantly decreased by 35.63% and 38.00% under mixed cropping conditions. Under the TJ treatment, the total biomass of a single plant of *A. conyzoides* was significantly increased by 78.30%, the underground biomass was 2.79 times that of monoculture, and there was no significant difference between aboveground and monoculture. Under TB and TG mixed cropping, the plant height and root length of *T. repens* and *F. arundinacea* had no significant change compared with monoculture, and the mixed cropping significantly increased the plant height of *A. conyzoides*. Under TB and TG mixed cropping, plant height and root length of Trifolium repens and Festuca arundinacea had no significant change compared with monoculture, and the mixed cropping significantly increased the plant height of *A. conyzoides.*

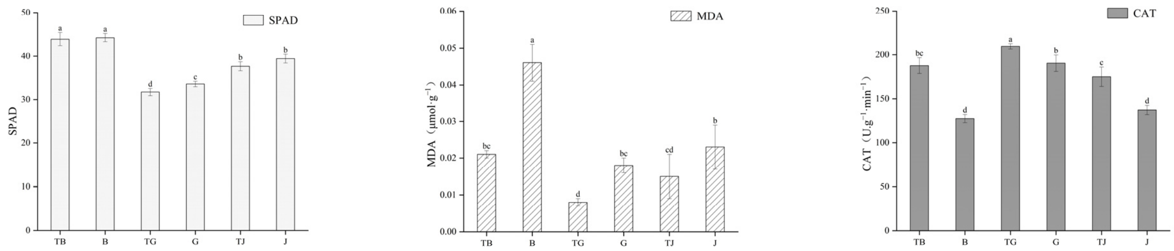
Table 4. Growth index of Cr-tolerant garden plants.

Plant name	Treatment Number	Individual Biomass/g	Aerial Biomass/g	Ground Biomass/g	Plant Height/cm	Root Length/cm
T. repens	TB	4.83 ± 0.54a	2.69 ± 0.35b	2.14 ± 0.23a	19.49 ± 0.15b	10.85 ± 0.45a
	B	4.76 ± 0.38a	3.09 ± 0.29ab	1.66 ± 0.44b	17.10 ± 2.22bc	11.06 ± 0.49a
F. arundinacea	TG	2.78 ± 0.57b	2.15 ± 0.31c	0.63 ± 0.27cd	52.12 ± 3.37a	11.64 ± 2.96a
	G	4.32 ± 0.28a	3.47 ± 0.25a	0.86 ± 0.03c	54.65 ± 0.23a	10.87 ± 0.35a
A. conyzoides	TJ	2.66 ± 0.28b	1.38 ± 0.14cd	1.29 ± 0.16c	19.08 ± 1.37b	9.89 ± 0.82a
	J	1.49 ± 0.25c	1.04 ± 0.21d	0.46 ± 0.11d	15.51 ± 0.12c	10.72 ± 0.90a

Note: different letters in the same column in the table indicate that the difference between different treatments is significant ($p < 0.05$). The data in the table are the mean ± standard deviation of 3 repetitions.

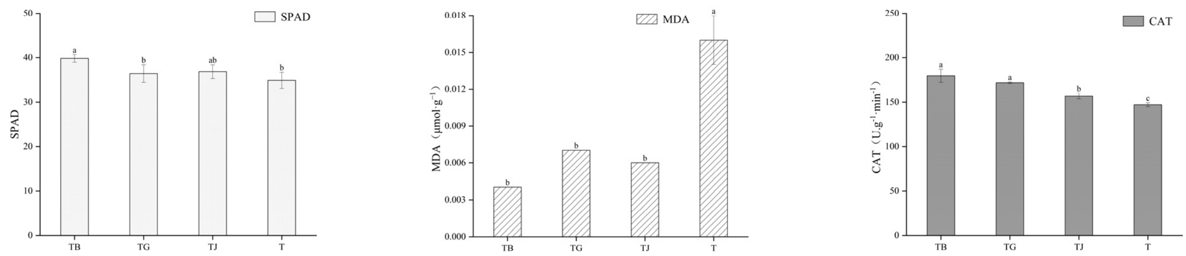
3.2. Effects of Mixed Cropping on Plant Physiological Indexes

Figure 1 shows that the mixed cropping had little effect on the SPAD value of chlorophyll in the leaves of *T. repens* and *A. conyzoides.* Compared with the monoculture, the SPAD value of chlorophyll in *F. arundinacea-B. parachinensis* was significantly reduced by 1.91 units. The malondialdehyde content of the TB, TG and TJ treatments was significantly lower than that of their monocultures, which decreased by 55.05%, 54.98% and 36.44%, respectively. The difference between TG and TB and between TG and TJ was significant, and there was no significant difference between TB and TJ. The *T. repens* monoculture treatment was significantly higher than the other treatments ($p < 0.05$). Mixed cropping had a significant effect on the catalase activity in the leaves of the three garden plants. Compared with monoculture, the catalase (CAT) content in the leaves of *T. repens*, *F. arundinacea* and *A. conyzoides* increased by 47.17%, 10.12% and 27.67%, respectively. Figure 2 shows that the chlorophyll content of *B. parachinensis* leaves treated with mixed *T. repens* increased by 4.9 units compared with monoculture. Mixed cropping significantly reduced the malondialdehyde content of *B. parachinensis* leaves. Compared with monoculture, the TB, TG and TJ treatments decreased by 72.56%, 58.90% and 62.21%, respectively. There was no significant difference between mixed cropping treatments. Compared with monoculture, the catalase content of *B. parachinensis* treated with TB, TG and TJ decreased significantly by 22.14%, 16.87% and 6.62%, respectively. The CAT content of *B. parachinensis* treated with TJ was significantly different from that of TB and TG ($p < 0.05$).



(**a**) SPAD (**b**) MDA (**c**) CAT

Figure 1. Changes in physiological indexes of Cr-tolerant garden plants under different treatments. Note: different letters in the same column in the figure indicate that the difference between different treatments is significant ($p < 0.05$). The data in the table are the mean ± standard deviation of 3 repetitions.

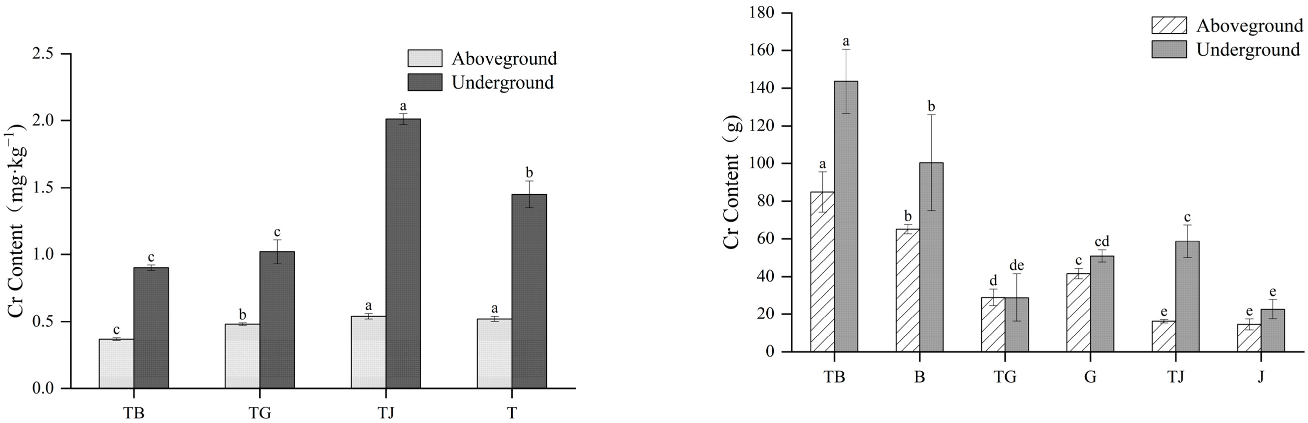


(**a**) SPAD (**b**) MDA (**c**) CAT

Figure 2. Changes in physiological indexes of Bra. under different treatments. Note: TB: Brassica parachinensis-Trifolium repens; TG: Brassica parachinensis-Festuca arundinacea; TJ: Brassica parachinensis-Ageratum conyzoides L.; T: Brassica parachinensi; MDA: Malonaldehyde; CAT: Catalase. Different letters in the same column in the figure indicate that the difference between different treatments is significant ($p < 0.05$). The data in the table are the mean ± standard deviation of 3 repetitions.

3.3. Effects of Mixed Cropping on Cr Content in Aboveground and Underground Parts of Plants

Under monoculture mode, the Cr contents in the aboveground and underground parts of *B. parachinensis* were 0.52 mg·kg^{-1} and 1.45 mg·kg^{-1}, respectively. As shown in Figure 3, intercropping with *T. repens* and *F. arundinacea* significantly decreased the Cr contents in the aboveground and underground parts of *B. parachinensis* by 28.18% and 7.79%, respectively (p < 0.05). The underground part decreased by 38.22% and 29.52%, respectively, and the Cr content in the underground part of the mixed *A. conyzoides* treatment increased significantly by 33.14%. The Cr contents in the aboveground parts of *B. parachinensis* were 0.37 mg·kg^{-1} and 0.48 mg·kg^{-1}, respectively, which were lower than the edible safety limit of Cr in vegetables (0.5 mg·kg^{-1}). Cr content in the aboveground and underground parts of garden plants was significantly affected by mixed cropping (p < 0.05). When mixed with *B. parachinensis*, Cr content in the aboveground and underground parts of *T. repens* increased significantly by 49.24% and 11.01%, and in *F. arundinacea*, Cr content in the aboveground part increased significantly by 12.24%, and Cr content in the underground part decreased significantly by 23.61%. The aboveground and underground parts of *A. conyzoides* were significantly reduced by 16.15% and 7.15%. There was a significant difference in Cr content between the TB, TG and TJ treatments (p < 0.05), shown as TB > TG > TJ.



(**a**) *B. parachinensis* (**b**) Cr-resistant garden plants

Figure 3. Cr content of plants under different treatments. Note: different letters in the same column in the figure indicate that the difference between different treatments is significant (p < 0.05). The data in the table are the mean ± standard deviation of 3 repetitions.

3.4. Effects of Mixed Cropping on Cr Enrichment Characteristics and TF of Plants

From Table 5, it can be seen that compared with monoculture, mixed cropping of *T. repens* and *F. arundinacea* significantly reduced the Cr enrichment ability of the aboveground and underground parts of *B. parachinensis*. When mixed with *T. repens*, the Cr enrichment coefficients of the aboveground and underground parts of *B. parachinensis* were significantly reduced by 28.18% and 38.22%, respectively (p < 0.05). When mixed with *F. arundinacea*, they decreased by 7.79% and 29.52%, respectively. When mixed with *A. conyzoides*, the Cr enrichment coefficient of *B. parachinensis* increased significantly by 38.91%, and the Cr enrichment coefficient of the aboveground part did not change significantly. The transport coefficient of Cr by *B. parachinensis* in the TG treatment was significantly increased by 31.07% compared with that in monoculture, and the transport coefficient of Cr by *B. parachinensis* in the TJ treatment was significantly decreased by 26.06%. Compared with monoculture, TB mixed cropping had little effect on the transport coefficient of Cr by *B. parachinensis* (p > 0.05).

Table 5. TF and BCF of Cr in *B. parachinensis* under different treatments.

Plant Name	Treatment	BCF		TF (Aboveground-Underground)
		Aboveground	Underground	
B. parachinensis	TB	0.002b	0.004c	0.417ab
	TG	0.002b	0.005c	0.472a
	TJ	0.003a	0.010a	0.266c
	T	0.003a	0.007b	0.360b

Note: different letters in the same column in the table indicate that the difference between different treatments is significant ($p < 0.05$). The data in the table are the mean ± standard deviation of 3 repetitions.

From Table 6, compared with monoculture, mixed cropping of *B. parachinensis* significantly increased the Cr enrichment coefficient of the aboveground and underground parts of *T. repens* by 49.24% and 11.01%, respectively ($p < 0.05$), and in *F. arundinacea*, the Cr enrichment coefficient of aboveground increased by 12.24%, and the Cr enrichment coefficient of underground decreased by 23.61%. The Cr enrichment coefficient of *A. conyzoides* aboveground and underground decreased by 16.15% and 7.15%, respectively. Mixed cropping with *B. parachinensis* significantly increased Cr translocation from root to shoot in *T. repens* and *F. arundinacea.* Under the TB and TG treatments, the TF of garden plants increased by 34.30% and 46.83%, respectively. There was no significant difference in the Cr enrichment coefficient and Cr transport coefficient between the aboveground and underground parts of *A. conyzoides* ($p > 0.05$).

Table 6. TF and BCF of Cr-tolerant garden plants under different treatments.

Plant Name	Treatment	BCF		TF (Aboveground-Underground)
		Aboveground	Underground	
T. repens	TB	0.157a	0.335a	0.470a
F. arundinacea	B	0106b	0.302b	0.440b
	TG	0.067c	0.226d	0.298c
A. conyzoides	G	0.060d	0.296b	0.203e
	TJ	0.059d	0.228d	0.257d
	J	0.070c	0.245c	0.284cd

Note: different letters in the same column in the table indicate that the difference between different treatments is significant ($p < 0.05$). The data in the table are the mean ± standard deviation of 3 repetitions.

3.5. Effects of Mixed Cropping on Soil Cr Content

As shown in Figure 4, compared with the monoculture of *B. parachinensis*, TB, TG and TJ significantly decreased the total Cr in soil by 24.31%, 14.80% and 5.9%, respectively, and there were significant differences among TB, TG and TJ. The total amount of Cr in soil treated with *T. repens* and *F. arundinacea* decreased to 150.56 $mg \cdot kg^{-1}$–175.03 $mg \cdot kg^{-1}$, which was 8.05% and 3.17% lower than that of monoculture, respectively. Compared with *B. parachinensis* monoculture, garden plants significantly reduced the content of available Cr in soil ($p < 0.05$). Compared with *T. repens* and *F. arundinacea* monoculture, mixed cropping of *B. parachinensis* significantly reduced the content of available Cr in soil by 81.74% and 73.54%, respectively. Compared with the monoculture of *B. parachinensis*, the remediation rates of Cr pollution in the soil treated with *T. repens* and *F. arundinacea* were significantly increased by 44.36% and 27.00%, respectively. The Cr pollution in the soil treated with *A. conyzoides* was not significantly improved. Mixed cropping increased the remediation rate of Cr-contaminated soil by *T. repens* and *F. arundinacea* and decreased the remediation rate of *A. conyzoides.* The remediation rate of soil Cr pollution by *T. repens* was significantly higher than that of *A. conyzoides.*

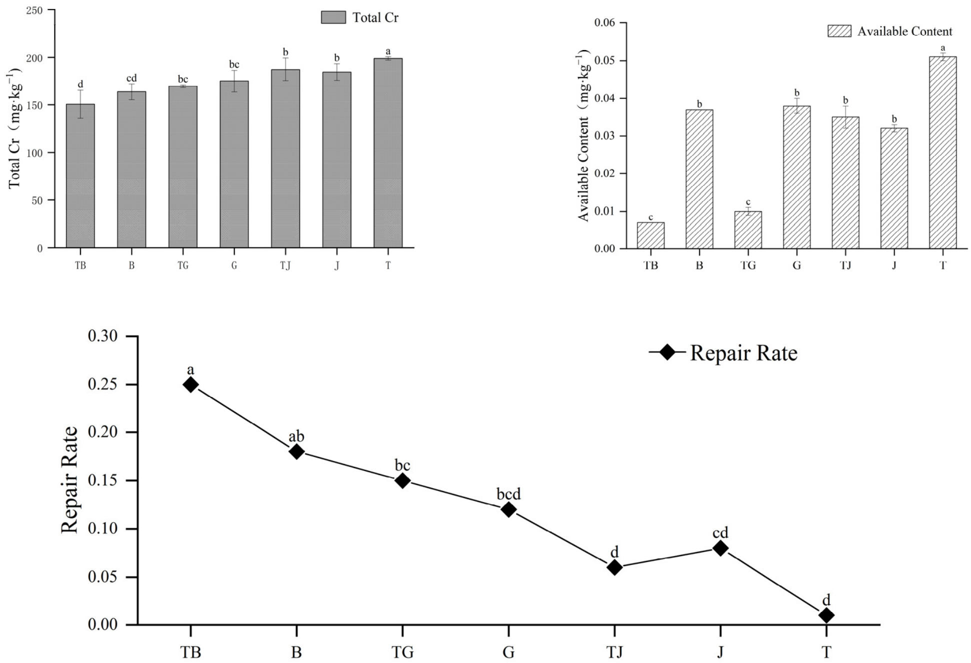


Figure 4. Changes in total Cr, available Cr and remediation rate in different treated soils. Note: different letters in the same column in the figure indicate that the difference between different treatments is significant ($p < 0.05$). The data in the table are the mean ± standard deviation of 3 repetitions.

4. Discussion

4.1. Effects of Mixed Cropping Patterns on Plant Growth and Physiological Response to Cr Stress

High concentrations of Cr will inhibit plant growth. This experiment showed that mixed cropping of *T. repens* and *A. conyzoides* significantly promoted the biomass of edible parts of *B. parachinensis*, which may be due to the fact that mixed cropping promoted the effective utilization of water, light and soil nutrients by plants, thus promoting plant growth [26]. At the same time, the mixed cropping of garden plants and economic crops increased the biomass of garden plants. This study found that the underground biomass of *T. repens* and *A. conyzoides* was significantly higher than that of their monoculture. Fengjiao Neng found that the garden plant Sedum plumbizincicola grew more vigorously than monoculture when celery and Sedum plumbizincicola were intercropped in cadmium-zinc contaminated soil, which was consistent with this study [27]. The growth of *B. parachinensis* was inhibited in the mixed cropping pattern of *B. parachinensis-F. arundinacea*, mainly because *F. arundinacea* developed fibrous roots that have significant advantages in nutrient competition and spatial competition [28].

Whether from the phenotype or physiological indicators, mixed cropping had a certain impact on plant growth and development in Cr stress. The results show that mixed cropping of Cr-tolerant garden plants promoted the positive response mechanism of *B. parachinensis* to Cr stress. Chlorophyll is an important substance for the photosynthesis of plants, and its content reflects the growth ability of plants [29]. In the mixed cropping system, the height of the plant may produce a mutual shielding effect to affect its receiving light, which may affect the photosynthesis of the plant and ultimately lead to differences in yield [30]. In the mixed cropping *T. repens* and *A. conyzoides* model, the chlorophyll content of *B. parachinensis* increased, which may be related to the significant increase in the plant height of *B. parachinensis*. The MDA in plant leaves will increase under external environmental stress [31]. This experiment found that the MDA of plants in the mixed mode decreased significantly, and the degree of membrane harm of leaves under Cr stress was reduced, which was consistent with the results of Yan Zhang [32]. CAT is an oxidase that resists membrane lipid peroxidation in plants and can prevent plants from potential oxidative damage. In this study, plant mixed cropping patterns effectively increased the CAT content, to protect themselves from Cr stress damage. Jixiu Wang [33] studied the physiological response mechanism of lead pollution in the intercropping system of low-accumulation maize and ornamental plant *Arabis alpina* Linn. The results show that the malondialdehyde in the intercropping system of maize and *Ara*. decreased significantly, and the catalase increased significantly, which was consistent with the results of this study.

4.2. Effects of Mixed Cropping Patterns on Plant Absorption of Cr and Soil Remediation Efficiency

Mixed cropping promoted the absorption of Cr by *T. repens* and *F. arundinacea* and promoted the transfer of Cr from underground to aboveground, which is conducive to the transfer of heavy metals to the harvestable parts of plants and facilitates the recycling of heavy metals. The garden plants *T. repens* and *F. arundinacea* intercropped with *B. parachinensis* can absorb and accumulate a large amount of Cr and can significantly reduce the absorption and accumulation of Cr by *Bra*. A patent [34] shows that Sedum and castor intercropping can play a role in repairing heavy metal pollution in soil, and this is a feasible repair mode that can reduce the content of pollutants in soil and, to a certain extent, increase energy plant production. This may be due to the low molecular weight of organic acids secreted by the roots of garden plants mixed with *B. parachinensis*, which may inhibit the absorption of heavy metals by economic crops [35]. In addition, under the mixed cropping mode, the interaction of interspecific competition increased the biomass, root length and plant height of economic crops and also increased the biomass, root length and plant height of garden plants. However, because the enrichment and transport capacity of heavy metals in garden plants was greater than that of economic crops, their roots will preferentially absorb and transport heavy metals and reduce the absorption and utilization of heavy metals by economic crops [24]. In TB and TG intercropping patterns, the enrichment coefficient and transport coefficient of *B. parachinensis* were smaller than those of chromium garden plants, and the enrichment and transport capacity of *T. repens* and *F. arundinacea* were significantly higher than those of monoculture. One study [36] found that the absorption capacity of heavy metals by hyperaccumulator and low-accumulator mixed cropping was significantly higher than that of hyperaccumulator monoculture. The Cr content in the edible parts of *B. parachinensis* was less than the safety limit of Cr content in vegetables in food safety (0.5 $mg \cdot kg^{-1}$), and the reduction effect of mixed cropping *T. repens* was the best, which was reduced to 0.37 $mg \cdot kg^{-1}$, which had strong application value. In the mixed cropping mode, *A. conyzoides* reduced the absorption of Cr and the enrichment coefficient, and the yield of *B. parachinensis* was not significantly affected, but the Cr content in the edible part exceeded the standard. *A. conyzoides* is not suitable for planting as a combination of enrichment plants and *B. parachinensis*, which may be due to the weak accumulation of Cr by *A. conyzoides*. The enrichment ability and transport ability of *A. conyzoides* were significantly lower than those of the other two plants in Cr-tolerant garden plant monoculture. Mixed cropping plays a certain role in regulating the total and available contents of Cr in soil. The available heavy metals in soil are easier to transform and migrate than the total heavy metals [37]. The results show that the total Cr content and available Cr content of soil planted with Cr-tolerant garden plants were significantly lower than those of *B. parachinensis* monoculture, and the remediation rate of soil Cr pollution was high. The reduction effect of *T. repens* was the most obvious, followed by *F. arundinacea*, and *A. conyzoides* was the worst, which was found when Aiyun Wang [38] explored *T. repens* and *F. arundinacea* for Cr accumulation. *T. repens* and *F. arundinacea* had a good accumulation effect on Cr, and the enrichment ability of *T. repens* to Cr was greater than that of *F. arundinacea*, which was consistent with the results of this study. Mixed cropping increased the remediation efficiency of *T. repens* and *F. arundinacea* on soil Cr pollution but did not change significantly. *A. conyzoides* is a Cr-tolerant plant that can maintain good growth in Cr-contaminated soil [39]. We found that *A. conyzoides* has a certain effect on Cr-contaminated soil remediation, and mixed cropping has no significant effect on its remediation efficiency. Therefore, intercropping can improve the remediation rate of soil Cr pollution by garden plants, which is TB > TG > TJ. After the plants are harvested, the content of soil Cr in TB intercropping decreases from 200 mg·kg^{-1} to 150.56 mg·kg^{-1}, which has potential application value compared with the screening value of 150 mg·kg^{-1} (pH between 5 and 7.5) for Cr in the standard for *Risk Control of Soil Pollution on Agricultural Land (Trial)* (GB15618-2018).

5. Conclusions

In Cr-contaminated soil, the mixed cropping of *T. repens* and *A. conyzoides* can promote the growth of the beet heart and maintain its own good growth, showing good benefits in terms of growth indicators and physiological indicators. Compared with single plant planting, Cr in mixed cropping was highly accumulated. Plants absorbed heavy metals in soil and reduced the absorption of heavy metals by vegetables. This way can reduce the Cr content in edible parts of vegetables and ensure the food safety of vegetables [40]. In the past, most agricultural gardens were mainly planted with a single crop. Gardeners enrich the planting methods of crops in the garden which can be more sensitive to the reaction of plants to external environmental factors. Cr is mostly produced in the process of industrial production, discharged into the air to cause pollution, and pollutes the soil through air sedimentation [41]. The health of the soil has a vital impact on the plant growth of the community garden. High-accumulation plants can not only help to produce healthy and safe vegetables but also repair heavy metal pollution in soil. However, not all high-accumulation plants can play the role we want through this mixed cropping mode. There may be competition between plants. Some vegetables will reduce the repair effect of high-accumulation plants under mixed cropping conditions. This requires us to conduct a large amount of plant research and screen out appropriate plant combinations.

From the perspective of global climate change, the main causes of climate change due to air pollution are mainly the greenhouse effect caused by carbon dioxide in the atmosphere [42], and the possible release of heavy metals in soil is not considered much. In fact, as detectors of climate change, plants can quickly feel the change in the weather [43]. Community gardens increase concern about climate change through residents' participation in plant planting. They may pay more attention to the impact their behavior may have on global climate change in their daily life, such as practicing low-carbon travel and reducing the use of air conditioners and garbage production. From the perspective of coping with global climate change, optimizing the planting pattern of plants that can repair the heavy metal pollution in the soil of community gardens is of great significance for the microclimate construction of community gardens, the environmental protection awareness of residents and monitoring and preventing the possibility of heavy metal pollution in the atmosphere, and more scholars should pay attention to it in the future.

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