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Effect of anaerobic fermentation residues on a chromium-contaminated soil-vegetable system

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Abstract

Wastewater irrigation and the deposit of chromium residues during the course of chromate production had caused serious chromium pollution in farmland. The aim of this study was to use anaerobic fermentation residues to treat with a chromium-contaminated soil-vegetable system. Pot experiment with Chinese cabbage, indoor cultivation experiment and soil adsorption experiments were conducted in this study. The results indicated that both yields and residual chromium in Chinese cabbages with the treatment of anaerobic fermentation residues were generally better than that with the treatment of chemical fertilizer. At the second experiment, compared with raw soil, mineralized potential and mineralized rate of nitrogen increased 29.2% and 15.4% respectively after adding anaerobic fermentation residues. Experimental results were fitted to Langmuir equation, Freundlich equation and Temkin equation, Langmuir equation was found to be the best to describe the adsorption of phosphor, and Temkin equation was the fittest for describing the adsorption of potassium. The supply of nitrogen, phosphor and potassium from soil were enhanced in varying degree (nitrogen > phosphor >potassium). Thus anaerobic fermentation residues may be considered as a widespread, effective and safe strategy for deal with chromium-contaminated soil-vegetable system in future.

Keywords: Chromium contamination; Soil-vegetable system; Anaerobic fermentation residues

1. Introduction

With the development of modern agriculture, more and more chromium enters into the environment. Diffusing chromium dust, cumulative chromium residues and chromium wastewater irrigation have caused large amount of soil pollution. As a mainly contaminant element, the residence time of chromium in soils is estimated to be 10^3-10^4

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years [1]. The accumulation and enrichment of chromium make it even go into terrestrial ecosystems, which results in potential toxicity. However, it is more hazardous that chromium contamination in soil-vegetable system is covert, long-term and irreversible [2]. It indirectly not only effect vegetable yield and quality, but also harmful to human life and health through food chain.

Owing to the importance of chromium contamination, many studies about them have been carried out. The conventional methodologies for soils contaminated with chromium are water extraction, electrochemical method [3-4], replacing soil, cultivating plants with strong resistance to chromium [5], using self-support microorganisms [6-7] or adsorption, etc. However, most of them suffer from high costs associated with energy, manpower, materials or financial resources and with some kinds of limitations. In recent years, diverse materials were used to chromium-contaminated soil remediation. In this respect, lime, phosphate, zeolite, manure, compost, ammonium bicarbonate, organic fertilizer or fly ash [8] have been suggested for the in situ remediation of chromium-contaminated soil. In particular, organic matter is an effective and economical remediation material for chromium-contaminated soil [9-10]. According to Chien-Chih Chiu, et al., materials consisting of large amounts of dissolved organic carbon and easily be decomposed are good candidates for amending Cr(VI)-contaminated soils [11]. Anaerobic fermentation residues are high-quality organic fertilizer, which can improve the physical, chemical properties and the permeability of the soil. The humus substance is an important chelant or complexant. As organic manure added into soil, functional group of humus can release H^+ with negative electricity, which can adsorb heavy metal and influence ion exchange reaction [9]. Further more, the movement of chromium is associated with its oxide state, Cr (Ⅵ) transforms into more stable Cr (Ⅲ) is a key progress, organic matter and fertilizers can change the state of heavy metals to reduce its toxicity and promote the removal of chromium [12-13].

The aim of this paper was to investigate, under laboratory conditions, the effect of anaerobic fermentation residues on a chromium-contaminated soil-vegetable system. We conducted pot experiment for Cr (VI) biosorption by anaerobic fermentation residues and chemical fertilizers of Chinese cabbage at various initial Cr (VI) concentrations and quantity of above two matters. Further more; indoor cultivation experiment and soil adsorption experiment were applied to analyze mineralizing of nitrogen, adsorption of phosphor and potassium after adding anaerobic fermentation residues into chromium-contaminated soil. Kinetic and Isothermal adsorption models were used to describe adsorption of phosphor and potassium in chromium-contaminated soil. It is expected to be helpful for securely, economically treating with chromium contamination and effectively utilizing agricultural waste.

2. Material and methods

2.1. Experiment material

Raw soil used in the experiment was taken from farmland in Xiedao ecological holiday village of Beijing, China, which was sieved through 3mm mesh sieve. Anaerobic fermentation residues containing abundant nutrient substance and living creatures were taken from a biogas reactor with chicken manure as fermentation material of Liuminying ecological farm in Daxing district of Beijing, China. $K_2Cr_2O_7$ was used as chromium source in the form of analyzing pure. The mixture of the raw soil and $K_2Cr_2O_7$ was used as the test soil. Physical and chemical properties of soil and anaerobic fermentation residues were showed in Table 1 and Table 2.

Table 1 The physical and chemical properties of soil

Organic matter (%)	NH_4^+-N (mg/kg)	Available phosphorus (mg/kg)	Available potassium (mg/kg)	Humic acid (%)	pH value	Total chromium (mg/kg)
1.32	8.50	55.00	143.50	2.37	7.24	50.60

Table 2 The physical and chemical properties of anaerobic fermentation residues

TN (%)	TP (%)	Organic matter (%)	pH value	Total chromium (mg/kg)
3.81	2.98	36.50	7.84	26.37

2.2. Experiment design

Two experiments were conducted in this study. One was pot experiment using Chinese cabbage with 10 treatments and a control. According to different Cr (Ⅵ) concentration of soil adding the same anaerobic fermentation residues to comparatively analyze the growth of cabbage and study the effect on detoxification effect of anaerobic fermentation residues, as well as effect on Cr (Ⅵ) concentration to anaerobic fermentation residues. At the same time, chemical fertilizers and anaerobic fermentation residues were applied to chromium-contaminated soil respectively to analyze detoxification effect of anaerobic fermentation residues. Anaerobic fermentation residue is one kind of slow-action fertilizer, as well as ordinary organic fertilizer, which can be used as basic fertilizer or top dressing. Anaerobic fermentation residues and chemical fertilizer in the form of basic fertilizer were in accordance with the required amount of cabbage respectively. Mixtures of fertilizer and test soil were put into a gray tile pot of 40cm-high and 25cm-diameter. Each pot had 4.5kg soil samples. The amount of Cr (Ⅵ) concentration, anaerobic fermentation residues and chemical fertilizer were shown in Table 3. Cabbages leaves were regularly observed at Sep.16, Oct.1, Oct.18, Oct.28 and Nov.11. Accumulative yield for 2 months after planting time (Sep.15) was recorded. Quantity of leaves and yields of cabbage may show the effect of anaerobic fermentation residues on cabbage growth. Chromium residue in cabbage may show the effect of anaerobic fermentation residues on cabbage quality using graphite atomic absorption method.

Table 3 Design parameters of pot experiment

Treatment	Cr (Ⅵ) concentration (mg/kg)	Anaerobic fermentation residues (g/pot)	Fertilizers (g)		
			$CO(NH_2)_2$	KH_2PO_4	K_2SO_4
Control	0	0	0	0	0
1	0	0	3.21	1.36	3.28
2	10	0	3.21	1.36	3.28
3	20	0	3.21	1.36	3.28
4	30	0	3.21	1.36	3.28
5	40	0	3.21	1.36	3.28
6	0	258	0	0	0
7	10	258	0	0	0
8	20	258	0	0	0
9	30	258	0	0	0
10	40	258	0	0	0

Indoor cultivation experiment and soil adsorption experiment included three different experiments (mineralizing of nitrogen, adsorption of phosphor and potassium). Each experiment had three treatments (S0, S1 and S2) and was carried out in triplicate. Experimental design was shown in Table 4. Amount of anaerobic fermentation residues was the same as pot experiment. Concentration of Cr (Ⅵ) was 20 mg/kg (medial concentration of pot experiment was chosen for this experiment).

Table 4 Design parameters of indoor cultivation experiment and soil adsorption experiment

Treatment	Cr(Ⅵ) (mg/kg)	Anaerobic fermentation residues (g/kg soil)
S0	0	0
S1	20	0
S2	20	57

2.3. *Analysis method of nitrogen mineralizing*

Nitrogen mineralization was a biochemical progress with microorganisms, in which organic nitrogen transferred into mineral nitrogen to provide available nitrogen to plant [14]. In other words, it was positive correlation between absorptivity of nitrogen and mineralized amount of soil. Nowadays two ways were used commonly for studying nitrogen mineralization. One was indoor cultivation experiment which was of great advantage for exploring regularity of nitrogen mineralization. The other was in-situ field measure, variation of inorganic nitrogen and amount of nitrogen absorbed by plant were used to calculate actual mineralization amount in field without nitrogen fertilizer [15]. Indoor cultivation method invented by Stanford was used in this study [16]. The diameter of the plastic self-made filtering pipe was 2.5cm with 14cm long. A rubber stopper of 7mm covered with double-deck white gauze placing in lower side of the pipe. Clean arenaceous quartz (diameter<2mm) were spread out about 2cm under the pipe in order to prevent soil scatter while leaching. The soil was air dried and sieved through 2mm mesh sieve. 15g soil together with identical amount of arenaceous quartz (0.9mm) and 0.01mol/L$CaCl_2$ solution were mixed, which were laid in filtering pipe at loose condition. 2cm clean arenaceous quartz (diameter<2mm) were covered on soil to insure tightly contact soil and arenaceous quartz. 100mL 0.01mol/L$CaCl_2$ was used to leach mineral nitrogen of soil, and then 0.002mol/L $CaSO_4{\cdot}2H_2O$; 0.002mol/L $MgSO_4$; 0.005mol/L Ca ($H_2PO_4{\cdot}2H_2O$); 0.0025mol/L K_2SO_4 was used to leach incubation solution without nitrogen. Redundant water was extracted by vacuum pump. Plastic film was used for sealing (a middle hole with diameter<1mm for air draft). Incubation temperature was at constant temperature (35±1℃). Following the same method, mineral nitrogen was reclaimed again in the 1,3,4,6,8,12,16,20,24 week of incubation time.

Through long-term and intermittent leaching incubation experiment, Stanford and Smith obtained first-order kinetic equation, which had been widely used to describe dynamics of nitrogen mineralization for a variety of kinds of soils, land-using patterns, crops and climate conditions. A large number of researchers validated the dynamic model, which well described characteristics of nitrogen mineralization and relationship between amount of cumulative net mineralization and incubation time. Stanford and Smith firstly used mineralization potential (N_0) and mineralization rate (k) to describe nitrogen mineralizing.

First-order equation based on standardized kinetic model, conventional model was as follows:

$$N_t = N_0(1-e^{-kt}) \tag{1}$$

In which N0 was the mineralization potential of soil (mg N/kg); N_t was cumulative amount of nitrogen mineralization in incubation time t (week) (mg N/kg); and k was nitrogen mineralization rate constant (/week).

2.4. Isothermal curve of phosphor adsorption

Amount of phosphor in soil was closely connected with valid phosphor and movement of phosphor. Phosphor adsorption could well describe the mobility of Phosphor in soil. 5.00g soil air dried and sieved through 1mm mesh sieve adding 50ml $CaCl_2$ with concentration of 0.01mol/L and KH_2PO_4 of different concentration (10,20,30,40,50,60 mgP/L) were laid in 250mL triangle flask for each treatment. Three drops chloroform was added to above mixture to inhibit microbial activity. Triangle flasks stuffed up and oscillated to and fro for 30 min under constant temperature of 25℃, twice a day in a two-day period for adsorption equilibrium. Then suspending liquid were poured into centrifugation tube at 3000rpm for 15min. Supernatant liquor were taken to mensurate phosphorus content of balanced solution by molybdenum blue colorimetry. Subtractive method was used to calculate adsorptive phosphorus content of soil in KH_2PO_4 with different concentration. Phosphorus adsorption isotherm of soil was obtained, taking adsorptive capacity of phosphorus as y-coordinate and phosphorus concentration of balanced solution as x-coordinate.

2.5. Analytical method of potassium adsorption

5.00g soil air dried and sieved through 1mm mesh sieve adding 50mL $CaCl_2$ with concentration of 0.01mol/L and KCl with different concentration (5, 10, 20, 30, 40, 50mg P/L) were laid in 250 mL triangle flask for each treatment. Triangle flasks stuffed up and oscillated to and fro for 30 min under constant temperature of 25℃, twice a day in a two-day period for adsorption equilibrium. Then suspending liquid were poured into centrifugation tube at 3000 rpm for 15 min. Supernatant liquor were taken to mensurate potassium content of balanced solution by atomic absorption spectroscopy.

2.6. Isothermal adsorption equation

Absorption firstly occured physical or chemical process, as gassy or liquid pollutants diffused and migrated to soil surface. Adsorption isotherms were all non-linear [17]. Mathematic model like Langmuir equation, Freundlich equation and Temkin equation were commonly used for describing soil adsorption.

Langmuir theory designed to show that absorbent and releasable amount come to banlance in unit surface area and unit time [18]. It was firstly used to describe absorption of gas, its prerequisites were different from soil conditions, but it was widely used as an empirical regression equation. Freundlich equation was widely used in chemical engineering, soil and other studies. When adsorptive multi-site worked at the same time, each adsorptive sites showed a different free absorptive energy and quantity of remnant sites.

Above three equations were used to fit to phosphor adsorption and potassium adsorption.

Langmuir equation: $$C/X = 1/kX_m + C/X_m \quad (2)$$

Where X was adsorptive quantity of phosphor and potassium (μg/g), C was concentration of balanced solution (mg/L), k was constant of binding energy between adsorbent and adsorbate, Xm was maximal adsorptive quantity (μg/g).

Freundlich equation: $$\lg X = 1/n \lg C + \lg K \quad (3)$$

X and C in Freundlich equation had the same meaning with that in Langmuir equation. K and n were empirical constant, which related to adsorptive quantity and adsorptive intensity respectively.

Temkin equation: $$X = A + B\lg C \quad (4)$$

Where X and C had the same above-mentioned meaning, A and B were both constant of adsorptive heat. R^2 (correlation coefficients) could be used to describe correlation of fitting equation.

3. Results and discussion

3.1. Effect on growth of chromium-contaminated cabbage by anaerobic fermentation residues

The quantity of leaves and yields of Chinese cabbage in the whole growing process are shown in Fig.1and Fig.2. With different chromium content in soil adding equivalent anaerobic fermentation residue, treatment 7 has the best growth and the highest yield among treament 6, 7, 8, 9, 10. Growth of tretment 7 (Cr (Ⅵ) concentration of 10 mg/kg) and tretment 8 (Cr (Ⅵ) concentration of 20 mg/kg) are higher than that of the control, however, tretment 9 (Cr (Ⅵ) concentration of 30 mg/kg) and tretment 10 (Cr (Ⅵ) concentration of 40 mg/kg) have lower yeild than the control. On one hand, it is indicated that chromium with low concentration can stimulate the growth of vegetables and increase its yield; however, chromium with higher concentration may inhibit nitrification of organic matter in soil, even effect the growth of Chinese cabbage. On the other hand, anaerobic fermentation residue is a kind of high-quality organic fertilizer, which plays an inportant role of fertilizer efficiency to advance growth of Chinese cabbage. At the same time it has some detoxification effect for chromium pollution.

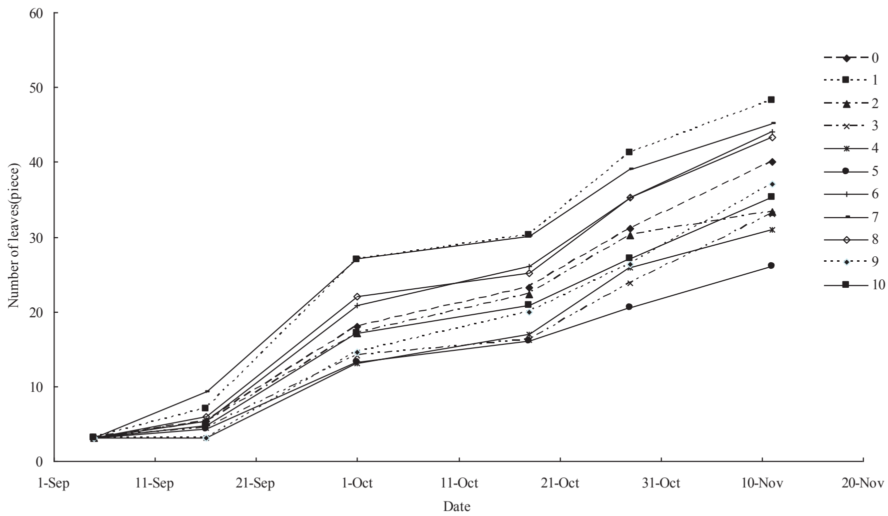

Fig.1 Leaf change of Chinese cabbage

It is evident to see that Chinese cabbage of treatment one has the best growth and the highest yield, owing to non-chromium contamination of soil and efficiency of chemical fertilizer. According to Fig.2, it is clear that growth condition and final yeild of treatment 7,8,9,10 containing anaerobic fermentation residues are much better than that of treatment 2,3,4,5 with chemical fertilizers at the same chromium concentration in soil, and its average output increased 66.2%. For example, yeild of Chinese cabbage with Cr (Ⅵ) concentration of 40mg/kg (treatmet 10) adding anaerobic fermentation residues is higher than that with Cr (Ⅵ) concentration of 10mg/kg (treatmet 2) adding chemical fertilizers. The difference is about 32.5%. Through observation, we find that soil gets loose, surface roughness changs large and porous structure form after adding anaerobic fermentation residues. However, soil gets compaction, space changes less, parts of large block form, large fissures appear after dehydration while adding chemeical fertilizer. It is indicated that anaerobic fermentation residues can improve soil quality and owing to it the growth of Chinese cabbage has a greater improvement. Li et al. [19] add organic fertilizer to chromium-contaminated soil; the results show that organic fertilizer can significantly reduce toxicosis of carrot. When Cr (Ⅵ) concentration of soil is 0-30mg/kg, adding pig manure 37.5-75t / hm^2, yeild and residual chromium quantity of carrot are close to control value; As a result, it is showed that anaerobic fermentation residues is helpful for detoxification of Chinese cabbage in chromium-contaminated soil-vegetable system.

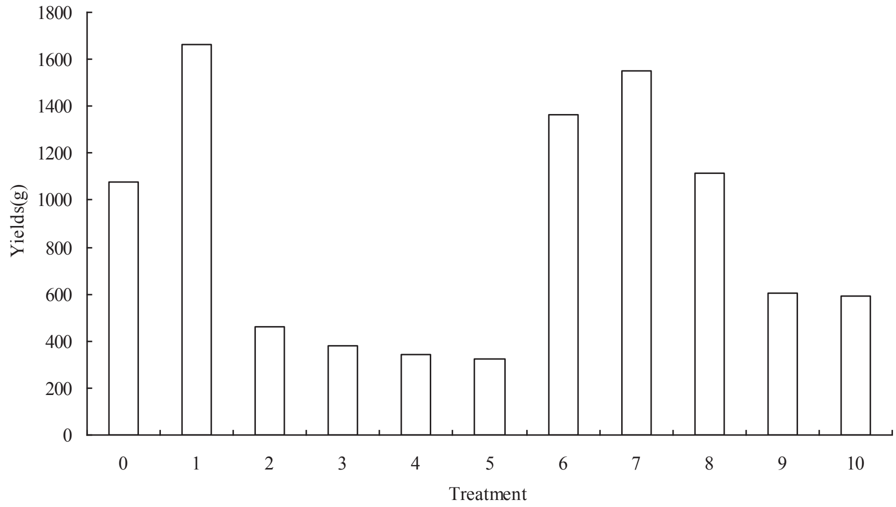

Fig. 2 Yield of Chinese cabbage

3.2. Effect on chromium residual quantity of Chinese cabbage by anaerobic fermentation residues

When chromium residue of vegetables is up to a certain extent, it will make a serious impact on human health, even worse it will lead to cancer. The maximum limit of chromium residue in vegetables is 0.5mg/kg. (Standard of limited chrome residue in food GB 14961-1994).

Fig.3 shows the residual quantity of chromium in Chinese cabbage after different treatments respectively. Our results indicate that in uncontaminated soil, either adding chemical fertilizers or anaerobic fermentation residue, chromium content in Chinese cabbage is slightly different from each other(＜0.5mg/kg). When chemical fertilizers and anaerobic fermentation residues are added to chromium-contaminated soil, chromium residues in Chinese cabbage of all treatments are over the maximum limited value. Chromium residues in cabbage increase with increasing chromium concentration of soil. In addition, adding anaerobic fermentation residues has a less chromium residue than treatment without anaerobic fermentation residues. It may be related to organic matter, which can reduce pH value of soil and the effectiveness of chromium. When Cr (Ⅵ) concentration in soil is from 10mg/kg to 40mg/kg, chromium residue in Chinese cabbage with adding anaerobic fermentation respectively reduced 25.1%, 27.3%, 11.7% and 42.9% compared with treatment of adding chemical fertilizer. Investigation has already shown that organic matter in organic fertilizer can make good use of enhancing adsorption of heavy metals by soil and reducing heavy metal residues in vegetables [20]. It is indicated that anaerobic fermentation residues can not only improve soil quality and crop conditions, as well as growth quality of vegetables.

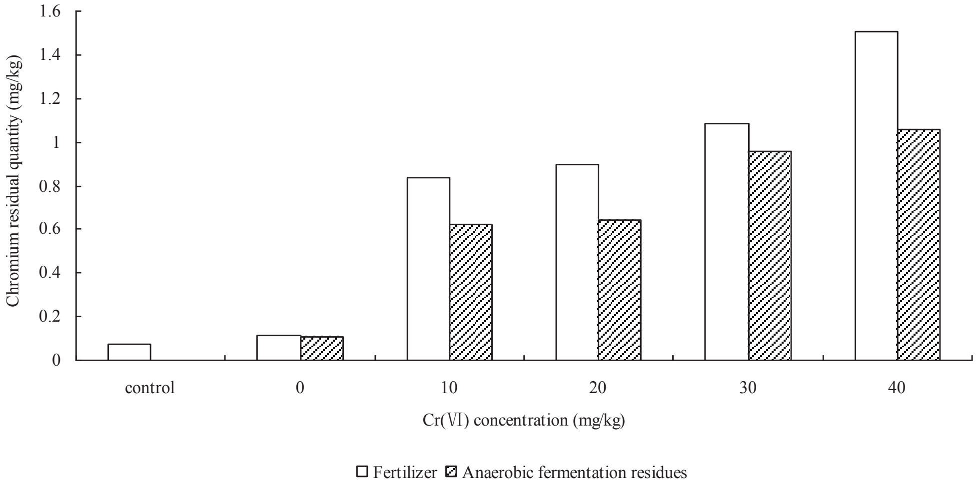

Fig.3 Residual quantity of chromium in Chinese cabbage

3.3. Effect of nitrogen mineralizing by anaerobic fermentation residues

3.3.1. Effect of nitrogen mineralizing capacity

Nitrogen mineralizing capacity in different incubation period is shown in Fig.4. Cumulative mineralizing capacity of three treatments is all increased within the whole incubation time, but it slightly increases in one unit of time, especially after approximately 10 weeks. Nitrogen mineralizing capacity of the three treatments is S2> S0>S1 (0.32, 0.40 and 0.79mg N/kg per week respectively). The results show that chromium can restrain nitrogen mineralization and reduce nitrogen supply. However, nitrogen mineralization capacity increases significantly after adding anaerobic fermentation residues.

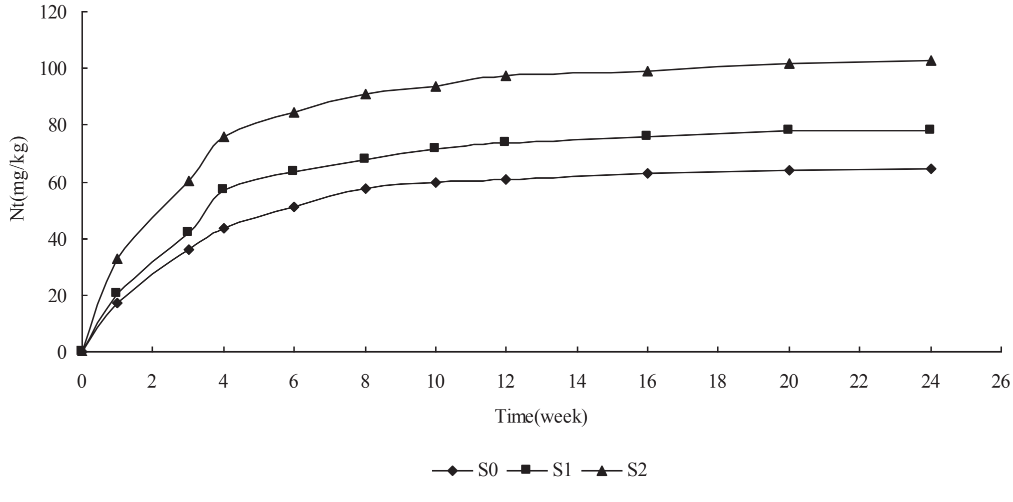

Fig. 4 Nitrogen mineralization curve of different treated soils

3.3.2. Effect of nitrogen mineralization potential and mineralization rate

Nitrogen mineralization curve can be approximately expressed by first-order kinetics equation (Eq. (1)), which can describe nitrogen mineralization process. The results for nitrogen mineralization potential and rate of different treated soils are obtained (Table 5).

Table 5 Nitrogen mineralization potential and rate in different treated soils

Treatment	N_0(mg N/kg)	Relative value (%)	k(/week)	Relative value (%)
S0	76.96	100.00	0.2888	100.00
S1	63.99	83.10	0.2825	97.80
S2	99.47	129.20	0.3334	115.40

Mineralization potential of soil (N_0) can be used to judge ability of nitrogen supply of various soil and measure nitrogen mineralization process and nitrogen supply capacity of vegetables in the growing period. It is positive correlation between N_0 and nitrogen supply. Constant of nitrogen mineralization rate (k) is a relative indicator to describe decomposition of organic nitrogen and speed of nitrogen mineralizing. Compared with S0, N_0 value is 83.1% and 129.2% of treatment S1and S2 respectively (Table 5). K value of S1 is close to S0, while k value of S2 is about 115.4% of S0. The results show that chromium leads to a decrease of mineralization potential of soil, but it is little impact on nitrogen mineralization rate. We can conclude that anaerobic fermentation residues can improve soil environment, accelerate decomposition of organic nitrogen and increase supply of nitrogen.

3.4. Effect of phosphorus adsorption by anaerobic fermentation residues

3.4.1. Phosphorus adsorption isotherm

In isothermal curve of phosphorus adsorption (Fig.5), adsorption curve can be divided into two portions. The first portion is region of fast absorption, in which phosphorus of chemical adsorption can be quickly adsorbed. The second portion is region of slow absorption, in which adsorption gradually weakens and solution becomes saturated eventually. When the concentration of balanced solution is very low, slope of isothermal curve is relatively large. As concentration of balanced solution increases, the slope gets small. It is generally believed that fast absorption can be attributed to chemical reactions and surface diffusion, while the slow absorption is related to pollutants diffusing to micropore of humus and inorganic minerals, reactive site with lower energy, as well as surface precipitation [1]. As concentration of balanced solution increases, adsorption quantities of all treatments increases and are different from each other. The different adsorption quantity (S1>S2> S0) may be due to the chromium and anaerobic fermentation residues. The results show that chromium impacts adsorption process of phosphorus and increase adsorption quantity. With the same chromium concentration, adsorption quantity of soil to phosphorus may reduce after adding anaerobic fermentation residues, but still more than S0. It is reported that when concentration of balanced solution is low, phosphor is held by adsorption site with “high adsorption energy” of soil. However, as the concentration of balanced solution is high, redundant phosphor can be adsorbed by adsorption site with “low adsorption energy” [21]. Therefore, chromium may make adsorption quantity or energy increase, but they both reduces after adding anaerobic fermentation.

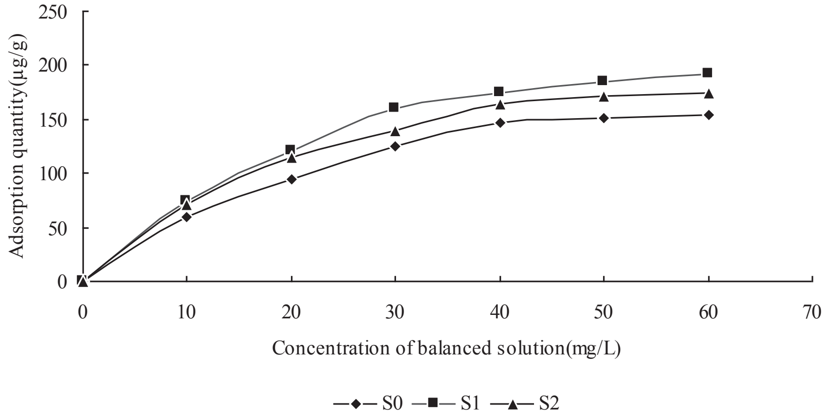

Fig. 5 Adsorption isotherm of phosphorus

3.4.2. Effect on parameter of adsorption isotherm

Langmuir equation, Freundlich equation and Temkin equation are used for analyzing and fitting the data of phosphorus adsorption. Experimental results are fitted to above three equations. The characteristic parameters of each model are obtained. Langmuir equation is found owing maximal R^2 value and to be the best equation for describing the adsorption of phosphor, as shown in Table 6. In Langmuir equation, both Xm or k value are S1>S2>S0. Phosphorus adsorption quantity and bond strength of solid-phase soil to soil solution are directly related to strength and quantity of phosphorus supplied to plant. The greater adsorption quantity and bond strength, the less phosphorus supplied. It indicates that chromium can increase phosphorus adsorption of soil and enhance bond strength. However, they reduce while adding anaerobic fermentation residues. Organic acid which decompounded by organic fertilizer can activate phosphorus of soil itself. Carbohydrates of organic fertilizer screen adsorption sites, so absorption of phosphorus for soil reduce [22].Therefore, the ability for soil to supply phosphorus improves.

Table 6 Fitting results of phosphorus adsorption equation

Treatment	Langmuir equation $C/X=1/kX_m+C/X_m$			Freundlich equation $\lg X=1/n \lg C+\lg K$			Temkin equation $X=A+B\lg C$		
	X_m	k	R^2	$1/n$	K	R^2	A	B	R^2
S0	188.68	0.109	0.9935	0.417	35.05	0.9641	-0.23	98.22	0.9737
S1	217.40	0.183	0.9987	0.351	56.57	0.9596	33.67	101.63	0.9829
S2	200.00	0.167	0.9975	0.348	51.43	0.9707	27.58	93.93	0.9875

3.4.3. Effect on maximal buffer capacity of phosphorus

Phosphorus buffer capacity is used for describing changing of solid-phase adsorptive phosphorus as phosphorus concentration of soil solution alters a unit. It is a synthetic indicator of available phosphorus of soil including quantity and strength of adsorptive phosphorus. Maximal buffer capacity (MBC) is maximal tangent slope of adsorption isotherm. It is equal to the value of Xm (maximal adsorption quantity in Langmuir equation) multiply k (parameter of adsorptive bond strength in Langmuir equation).

The MBC value of three treatments is S1>S2>S0 (Table 7). The results indicate that phosphorus fertility of soil is S0>S2>S1. When adsorptive buffer capacity increases, it means larger amount of phosphorus should be added to obtain the same phosphorus concentration of soil solution. It is negative correlation between concentration of available phosphorus and adsorptive buffer capacity. Anaerobic fermentation residues can decrease absorption buffer capacity of phosphorus in chromium-contaminated soil. At a similar adsorption quantity of phosphorus, compared to treatment without anaerobic fermentation residues, treatment with anaerobic fermentation residues has a lower adsorption strength and higher energy state. Therefore more available phosphorus can be supplied to vegetable.

Table 7 Maximum buffer capacity of phosphorus

Treatment	X_m	k	*MBC* (L/kg)
S_0	188.68	0.109	20.57
S_1	217.40	0.183	39.78
S_2	200.00	0.167	33.40

3.5. Effect on potassium adsorption by anaerobic fermentation residues

Potassium adsorption ability of soil and potassium supply ability of soil are negatively correlated. With the rising concentration of balanced solution, the adsorption quantity of three treatments increases. Their average adsorption quantity is 71.21μg/g, 77.01μg/g and 75.91μg/g respectively. Adsorption quantity of S1 and S2 increase by 8.1% and 6.6% compared with S0. Soil of S0 has the strongest ability for supplying potassium. The results indicate that chromium may enhance adsorption quantity of potassium and reduce ability for supplying potassium of soil. However, at the same amount of chromium, anaerobic fermentation residues may improve the situation.

All three equations are used to describe potassium adsorption for soil and results are shown in Table 8. Temkin equation is found to be the best to describe the adsorption of potassium. Parameter A expresses adsorption quantity and releasing amount of potassium on solid-phase surface of soil as potassium concentration of soil solution. Adsorption is positive value as well as release is negative value. A value of three treatments are all negative, which indicates that soil of each treatment release potassium from solid-phase surface of soil to soil solution under the condition of 1 mg/L soil solution. It may be explained that the releasing amount of potassium and potassium adsorption quantity for soil was negatively correlated. High potassium adsorption quantity for soil results in few releasing potassium and low ability for supplying potassium. Absolute value of parameter A is S0> S2> S1, which indicates that soil of S0 has the strongest ability for supplying potassium and chromium goes against releasing potassium to soil, however, anaerobic fermentation residues can improve potassium supply at a certain extent.

Table 8 Fitting results of potassium adsorption equation

Treatment	Langmuir equation $C/X=1/kX_m+C/X_m$			Freundlich equation $\lg X=1/n\lg C+\lg K$			Temkin equation $X=A+B\lg C$		
	X_m	k	R^2	$1/n$	K	R^2	A	B	R^2
S0	270.27	0.021	0.8080	0.8097	6.947	0.9592	-0.23	98.22	0.9737

S1	270.27	0.025	0.8677	0.783	8.362	0.9670	33.67	101.63	0.9829
S2	263.16	0.025	0.8377	0.7786	8.302	0.9600	27.58	93.93	0.9875

4. Conclusions

The application of anaerobic fermentation residues studied to a soil-vegetable system contaminated with chromium under laboratory conditions can promote growth of vegetables. Both yield and residual chromium were generally better of treatment with anaerobic fermentation residues than that with chemical fertilizer. Anaerobic fermentation residues is a antidote to chromium-contaminated soil at a certain. On the other hand, anaerobic fermentation residues can accelerate decomposition and release of organic nitrogen as well as enhance mineralization potential and mineralization rate obviously. At the same concentration of chromium, anaerobic fermentation residues could reduce adsorptive capacity, binding intensity and MBC of phosphorus in soil and improve phosphor supply and potassium supply at a certain extent. The results indicated that the addition of anaerobic fermentation residues may be considered as a widespread, effective and safe strategy for treat with chromium-contaminated soil-vegetable system remediation.

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