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Plants grown on sewage sludge in South China and its relevance to sludge stabilization and metal removal

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Abstract: The production of sewage sludge in China has been increasing sharply in order to treat 40% of the municipal sewage in 2005 as planned by central government. The main sludge disposal method is landfill owing to heavy metal contamination, but it presents an attractive potential for agricultural land application. Experiments were carried out to study the simultaneous metal removal and sludge stabilization by plants. The sludge samples were collected from Datansha Wastewater Treatment Plant of Guangzhou, it contained excessive Cu and Zn compared with the Chinese National Standard for Agricultural Use of Sewage Sludge. Plants growing on sludge beds were investigated to follow their growth and metal uptake. 30 sludge plants were identified during 1 year's observation. A Zn high-accumulating and high growth rate plant(*Alocasia macrorrhiza*) was selected and grown on sludge beds in plots. The water, organic matter, heavy metals and nutrients contents, the *E. coli* number and the cress seed germination index were monitored for the sludge samples collected monthly. The plant growth parameters and its heavy metals contents were also determined. The sewage sludge treated by plants could be stabilized at about 5 months, the *E. coli* number was significantly decreased and the cress seed germination index attained 100%. Crop on sludge could ameliorate the sludge drying. The experiments are continuing to find out the appropriate plant combination for simultaneous sludge stabilization and metal removal for an acceptable period. Comparisons between the proposed processes and other methods for treating produced sludge such as composting, chemical and bacterial leaching were discussed.

Keywords: sewage sludge; hyper-accumulator; heavy metal removal; stabilization

Introduction

About 10% of the municipal sewage was treated by 307 wastewater treatment plants in China at the end of 1999 and produced about 15000 tones of sewage sludge per day. The production of sewage sludge in China has been increasing sharply in order to treat 40% of the municipal sewage in 2005 as planned by central government (EPAC, 2000). The main sludge disposal method is landfill owing to heavy metal contamination. Cu and Zn contents in sewage sludge of China often exceed the national standards(GB4284-1984) of sewage sludge for direct agricultural land applications(Wu, 2000a). However, sewage sludge presents an attractive potential for agricultural land application (Wu, 1992; Mo, 2000), which is also the main disposal outlet in industrialized countries(Smith, 2000).

Reducing heavy metal contents in sewage sludge could be achieved by source control such as deepening the treatment of industrial discharges, engineering changes of wastewater treatment process (Elenbogen, 1987) and bio-sorption of heavy metals by the waste activated sludge returned to the primary clarifier(Wu, 2000b). Another method is the treatment of the produced sludge by chemical leaching (Cheung, 1988; Wu, 1998), bacterial leaching (Tyaqi, 1993; 1998). These treatments are often expensive or need establishment of additional installations in sewage treatment plants and cannot simultaneously stabilize the sewage sludge for agricultural application.

Phytoremediation, defined as the use of green plants to remove pollutants from the environment, is being considered as a new highly promising technology for the remediation of polluted sites(Baker, 1994; Brooks, 1998), especially remediating heavy metal contaminated soils by hyper-accumulators(McGrath, 2001; Gerard, 2000).

Experiments were carried out to stabilize sewage sludge by means of plants and meanwhile to remove

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heavy metals from sludge for agricultural recycling.

1 Materials and methods

The sludge samples were collected from Datansha Wastewater Treatment Plant of Guangzhou. It was the undigested but dewatered sludge and contained excessive Cu and Zn compared with the Chinese National Standard for Agricultural Use of Sewage Sludge. The chemical analysis of the untreated sludge is presented in Table 1.

Table 1 Chemical and biological analysis of the studied sludge

	Sludge. Ⅰ	Sludge Ⅱ	Sludge Ⅲ	Std. for agric. use*	
				pH < 6.5	pH > 6.5
Total Cu, mg/kg DM	248	259	210	250	500
Total Zn, mg/kg DM	1577	2268	1511	500	1000
Total N, g/kg DM	27.5	37.5	19.2		
Total P_2O_5, g/kg DM	39.2	47.0	38.4		
Total K, g/kg DM	10.4	14.7	15.6		
Organic matter, g/kg	272.1	383.7	274.0		
Water content, g/kg	787.9	830.8	800.2		
pH	6.04	6.14	5.82		
Germination index, %	0.69	125.1	95.0		
E. coli, MPN/g	9.5×10^4	5.43×10^6	5.00×10^6		

* Chinese national standard(GB4284-1984) of sewage sludge for agriculture use on the soils with soil pH < 6.5 and > 6.5 respectively

Sludge I was disposed into sludge bed in open air in July 2000 and the bed had a dimension of $(3 \times 5 \times 0.3)$ m^3. Volunteer wild plants were allowed to grow. In addition, corn (*Zea mays*, cultivar Chaotian-711) seeds were shown and 6 plants were retained growing. All the plants grown on sludge were identified, harvested and analyzed to get Cu and Zn contents in different parts of plants. Cu and Zn in plants were determined by atomic absorption spectrometer following the HNO_3-H_2SO_4-H_2O_2 digestion(0.5 g dry and ground plants with 2 ml concentrated H_2SO_4, 6 ml concentrated HNO_3 and 6 ml H_2O_2).

Following the above-mentioned experiment, a Zn high-accumulating plant(*Alocasia macrorrhiza*) was selected and grown on sludge beds measuring 1.5×2.0 m^2. The fresh dewatered sludge(Sludge Ⅱ) was replenished into beds at a height of 20 cm. The 1st experiment began in November 2000 and included 2 treatments: (1) control without plants; (2) with *Alocasia macrorrhiza*. The 2nd experiment began in April 2001 with the sludge Ⅲ and included 4 treatments: (1) control without plants; (2) with *Alocasia macrorrhiza*; (3) with naturally grown wild plants; (4) with *Alocasia macrorrhiza* and wild plants. 12 plants of *A. macrorrhiza* were planted for each bed. The experiments were undertaken out-door and in 3 replicates. The water, organic matter, Cu, Zn, N, P and K contents, the *E. coli* number and the cress (*Lepidium sativum*, *L.*) seed germination index (Zucconi, 1981) were monitored according to conventional methods(Page, 1982) for the sludge samples monthly collected from sludge beds. The plant growth parameters and its Cu, Zn, N, P and K contents were also determined at the end of each experiment.

2 Results and discussion

2.1 Sludge plants

30 plant species were identified on sludge bed during 1 year's observation and 11 main wild plants are demonstrated in Table 2. The sludge surface was covered by wild plants within 2 months in summer under the climate conditions of Guangzhou (subtropical zone). *Alternanthera philoxeroides* was the predominant species within 3 months and it has a prostrate stem with many roots so that it can cover the sludge rapidly and trap the sludge from run-off.

Alocasia macrorrhiza was the predominant species after 5 months and this plant accumulated more Zn than others, especially in underground parts. This plant could also keep growing in winter. One variety of this plant had significant tuber and this organ contained rather high Zn content and could be harvested.

In the other hand, the grains of corn(*Zea mays*) grown on untreated sewage sludge contained Cu and

Zn within the recommended interval for animal feeds(Coic, 1989). The Cu content in 5 of the 6 tested grain samples also conformed to Chinese National Food Standard(GB15199-1994: Cu < 10 mg/kg).

Table 2 Representative sludge plants and its Cu and Zn contents in Guangzhou, China

Plant species and organs	Cu		Zn		Analyzed sample number
	Range, mg/kg	Mean, mg/kg	Range, mg/kg	Mean, mg/kg	
1. *Alternanthera philoxeroides*					
Shoots	19.76—49.67	33.90	111.8—258.5	180.4	20
Roots	39.49—53.47	43.61	197.5—391.5	271.2	4
2. *Alocasia macrorrhiza*, variety 1					
Shoots	2.74—15.50	9.95	125.0—609.4	269.3	21
Roots	19.74—63.77	29.50	155.0— 755.0	366.1	5
3. *Alocasia macrorrhiza*, variety 2					
Leaves	16.49—16.89	16.69	145.0—154.9	145.0	3
Petioles	26.86 —28.54	27.47	264.9—290.0	276.6	3
Roots	50.20—51.10	50.79	1569.4—1609.0	1584.3	3
Tuber	25.66—29.28	27.87	1037.2 —1124.6	1113.7	3
4. *Boehmeria nivea*					
Shoots	10.74—17.24	14.10	57.47—465.6	237.6	7
Roots	20.24—62.75	37.28	92.47—796.9	292.7	5
5. *Commelina* communis					
Shoots	12.55—33.02	22.96	51.25—231.3	122.01	11
Roots	18.82 —114.5	49.25	119.3—483.5	277.2	10
6. *Echinochloa colona*					
Shoots	5.25—9.00	7.42	66.25—240.6	186.7	3
Roots	42.70—41.28	41.99	567.7—1060.7	814.2	2
7. *Gynura crepidiodes*					
Shoots	25.58—29.47	27.37	94.66—203.7	158.4	7
Roots		49.99		357.4	1
12. *Merremia hederacea*					
Shoots	12.98—14.74	13.67	99.92—108.7	104.3	4
Roots		33.43		385.2	1
8. *Oryza sativa*					
Shoots	5.75—7.50	6.58	120.0—609.4	618.1	3
Roots	61.79 —121.7	91.76	596.9— 1793.5	1195.2	2
9. *Salum nigrum*					
Shoots	9.17—29.05	16.43	92.47—608.8	194.1	9
Soots	14.66—70.96	31.39	185.0—1338.7	403.2	6
10. *Vetiveria zizanoides*					
Shoots	3.99—7.49	5.45	21.24—39.99	30.34	7
Roots	7.49—30.48	14.30	13.73—206.17	63.72	4
11. *Wadelia prostrata*					
Shoots	11.75—25.93	20.09	102.50—281.25	178.6	9
Roots	25.06—42.42	33.21	158.52—431.81	285.15	4
12. *Zea mays*					
Grains	4.49—10.99	8.16	62.47— 88.72	80.17	6
Leaves	4.25—12.49	8.85	145.0— 297.4	182.2	6
Stems	6.74—8.74	7.56	32.50—138.7	133.4	6
Roots	17.99—25.50	22.02	70.00—251.1	183. 54	4

From Table 2, significant difference in metal uptake and accumulation was observed between plant

species and between varieties. This might be caused by root physic characteristics (root radius, length, architecture etc.), biochemical mechanisms (uptake kinetics, root exudates, transportation forms etc.) (Lombi, 2001) and other physiological aspects such as water uptake (Wu, 1999). The detailed mechanisms for the plants studied in this experiment need to be elucidated. Further selection is necessary to obtain more interesting plants, for example, lower accumulating corn cultivar and higher accumulating *Alocasia macrorrhiza* variety, in order to realize effective plant treatment and transformation of metal contaminated sludge.

2.2 Sludge stabilization and metal uptake by plants

The sewage sludge treated by *Alocasia macrorrhiza* plants could be stabilized at about 5 months at winter-spring seasons (Table 3). After 5 months, the *E. coli* number was significantly decreased and the cress seed germination index re-attained 100%. The water content decreased significantly but no evident difference was recorded between the treatments with and without plants. It was similar for sludge pH. However, no significant variation was observed during 5 months for sludge organic matter, total N, P, K, Cu and Zn contents (Data omitted). The fact that the total Cu and Zn content remained stable is not similar to that observed in composting which generally concentrated these metals during composting (Simeoni, 1984) and this might be due to plant uptake and leaching loss of the metals.

Table 3 Changes of stability parameters during 5 months in winter-spring seasons for the sludges stored in the sludge beds without and with *Alocasia macrorrhiza* plants*

	No plants				With plants			
	E. coli, MPN/g	Water content, g/kg	*GI*#, %	pH	*E. coli*, MPN/g	Water content, g/kg	*GI*, %	pH
Nov. 00	5.43×10^6	830.8	125.1	6.14	5.43×10^6	830.8	125.1	6.14
Dec. 00	1.11×10^6	783.8	84.04	5.94	2.14×10^6	746.4	111.7	5.91
Jan. 01	4.83×10^5	744.7	78.86	5.73	6.98×10^7	776.7	60.70	5.58
Feb. 01	1.25×10^5	786.0	117.1	5.54	6.82×10^4	757.1	123.7	5.55
Mar. 01	9.53×10^4	713.1	136.9	5.34	8.48×10^3	706.7	122.5	5.53
Apr. 01	1.59×10^5	624.4	141.3	5.18	7.46×10^3	674.9	133.8	5.36

Notes: * All data were the means of 3 replicates; # *GI*: germination index of cress seed measured according to Zucconi *et al*. (Zucconi, 1981)

In summer-autumn seasons, the sludge layer dropped from 20 cm to about 5 cm, the sludge weight decreased from 450 kg to about 120 kg at the end of 7 months of experiment (at the beginning of winter) (Table 4). The planted sludge bed gave higher biomass and metals uptakes than other treatments. The changes of chemical and biological parameters of the sludge during the stabilization were rather similar to that in winter-spring seasons. The sludges with plants contained less than 20% of water at the end of the experiment and the water content decreased significantly more for the sludges planted with *Alocasia macrorrhiza* than that without plant and with wild plants (Fig. 1). At this moment, the *E. coli* was not more present in the sludges without wild plants but it still existed in weak number for the sludge beds with wild plants (Fig. 2). This might be caused by the existence of some partly degraded plant residues of the wild plants which died in later autumn in these treatments and these materials exhibited the *E. coli* growth. This was not true in the cases of control and planted beds. Concerning the phytotoxicity, all the

Table 4 Dry bio-mass, Cu and Zn uptake by aerial parts of the plants and sludge remained in sludge beds with different plant treatments for 7 months*.

	Control	Planted	Planted + wilds	Wilds
Dry biomass, kg/bed	—	1.149	0.874	0.420
Cu uptake, mg/bed	—	40.34	28.29	9.54
Zn uptake, mg/bed	—	159.89	116.11	68.58
Sludge remained #, kg/bed	129.9	119.1	119.0	116.2

Notes: * all data were the means of 3 replicates; # sludge remained in the bed from initial fresh sludge of about 450 kg

treated sludges enhanced the cress seedling's root elongation and so increased germination index(Fig.3).

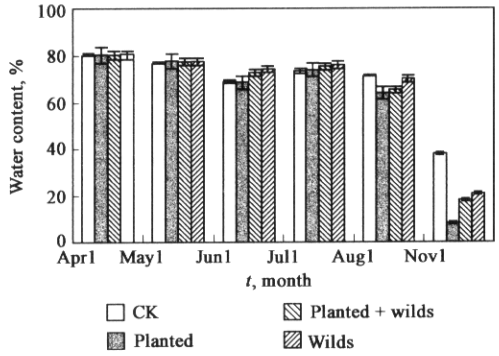

Fig.1 Changes of water content during summer-autumn seasons for the sludges stored respectively in the sludge beds without plants (CK); with *Alocasia macrorrhiza* plants (planted); with *Alocasia macrorrhiza* and wild plants (planted + wilds); with only wild plants(wilds). The error bars represent the standard deviation of 3 replicates

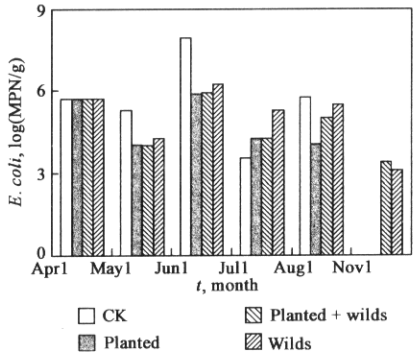

Fig.2 Changes of *E. coli* number during summer-autumn seasons for the sludges stored respectively in the sludge beds without plants (CK); with *Alocasia macrorrhiza* plants (planted); with *Alocasia macrorrhiza* and wild plants (planted + wilds); with only wild plants(wilds)

The Zn and Cd hyper-accumulator *Thlaspi caerulescens* was also successfully grown on the fresh or dried sludge in green house but the growth rate was significantly lower than normal plants. The metals taken up by the hyper-accumulator were under determination. The favorable effects of this plant on the sludge metal removal comparing with normal plants are expected but still to be verified.

Comparing with the composting by mechanic turning which required about 1 to 2 months to obtain acceptable seed germination index, this stabilization process was less expensive because it do not need dry organic matter input and power consumption. This process could also be cheaper than the chemical and bacterial leaching for removing heavy metals from sludge, which need chemicals input and re-dewatering.

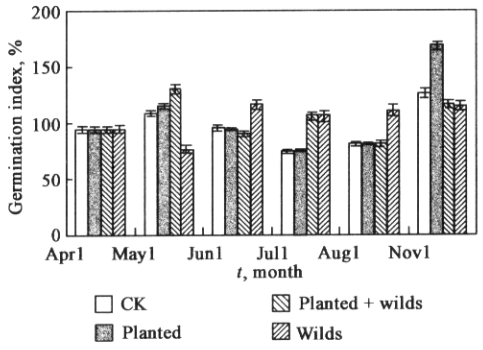

Fig.3 Changes of cress seed germination index during summer-autumn seasons for the sludges stored respectively in the sludge beds without plants (CK); with *Alocasia macrorrhiza* plants (planted); with *Alocasia macrorrhiza* and wild plants (planted + wilds); with only wild plants (wilds). The error bars represent the standard deviation of 3 replicates

3 Conclusions

Various plants can directly grow on sewage sludge in South China, some of these plants are interesting for treating the sewage sludges contaminated by heavy metals below certain concentrations. This is quite different to the municipal solid waste on which plants are generally difficult to set up. The Zn and Cd hyper-accumulator *Thlaspi caerulescens* can also directly grow on the studied sludge. The sewage sludge treated by plants could be stabilized at about 5 months. Further experiments are needed to find out the appropriate plant combination for simultaneous sludge stabilization and metal removal for an acceptable period, to estimate the favorable effects of hyper-accumulating plants on metal removal and to increase its growth and metal uptake.

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