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Short Communication

Using a high biomass plant *Pennisetum hydridum* to phyto-treat fresh municipal sewage sludge

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HIGHLIGHTS

- *Pennisetum hydridum* can not survive in fresh MSS, but it can if transplanted with a peat-based medium.
- This plant produces a high yield of biomass with low heavy metal content.
- After plant treatment, the MSS was dried, stabilized and can be considered to be landfilled or incinerated.

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ABSTRACT

The study was carried out to investigate the use of a high biomass plant, *Pennisetum hydridum*, to treat municipal sewage sludge (MSS). An experiment composed of plots with four treatments, soil, fresh sludge, soil-sludge mixture and phyto-treated sludge, was conducted. It showed that the plant could not survive directly in fresh MSS when cultivated from stem cuttings. The experiment transplanting the incubated cutting with nurse medium of *P. hydridum* in soil and fresh MSS, showed that the plants grew normally in fresh MSS. The pilot experiment of *P. hydridum* and *Alocasia macrorrhiza* showed that the total yield and nutrient amount of *P. hydridum* were 9.2 times and 3.6 times more than that of *A. macrorrhiza*. After plant treatment, MSS was dried, stabilized and suitable to be landfilled or incinerated, with a calorific value of about 5.6 MJ/kg (compared to the initial value of 1.9 MJ/kg fresh sludge).

1. Introduction

In order to treat the massive amount of waste generated from China's rapid population growth and industrialization, a large number of municipal waste water treatment plants (WWTPs) have been constructed. These plants discharges municipal sewage sludge (MSS), generating over 9.2 million tons of dry solid sludge annually in China. It is estimated that about 4% increase in total sludge production per year from an increase in WWTP construction. It was reported that only 3.5% of the MSS was incinerated, 34.5% was land-filled, 48.3% was applied to agricultural and forestry lands, and 13.8% was still waiting for disposal (Wang et al., 2006).

Safe disposal of MSS is one of the major environmental concerns. MSS has a huge potential as a useful resource due to its high content of nitrogen, phosphorus and organic matter (Martinez et al., 2003). MSS may be applied to agricultural land, forest, disturbed land or dedicated disposal sites (Bhogal et al., 2003; Walker et al., 2003). Land application of MSS has become one of the main outlets for MSS worldwide. However, the harmful ingredients of MSS such as heavy metals, pathogens, detergents, toxic organics, and hormone disruptors restrict fresh dewatered sludge to be applied for agricultural application (Aparicio et al., 2007; McGrath et al., 2000; Singh and Agrawal, 2008; Walker et al., 2003). Direct application of MSS and its composts to agricultural lands can lead to heavy metal contamination of soils and food. Increasingly, a viable alternative of MSS disposal is to utilize plants that are not used as food crops to uptake the toxics present in the MSS, thereby reducing the harmful effects of the MSS. The phyto-treated MSS can then be used safely as fertilizers for crop production.

Growing energy crops in heavy metals-contaminated MSS or soils is an excellent approach for both environmental and

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bio-energy issues. Hybrid Giant Napier (*Pennisetum hydridum*) was hybridized from elephant grass and African Pennisetum. It is an exotic multipurpose crop with high photosynthetic efficiency and strong drought-resistance, and has been used as an energy and forage grass (Liao et al., 2002; Ma et al., 2011). Additionally another plant, *Alocasia macrorrhiza*, which accumulates extremely high amounts of potassium (K) in its aerial parts is also used as a sludge plant (Wu et al., 2007).

The objectives of this study are: (i) to evaluate the survival and biomass yield of *P. hydridum* planted in fresh MSS; (ii) to compare the effectiveness of *P. hydridum* with *A. macrorrhiza* to uptake heavy metals and nutrients from MSS; and (iii) to evaluate the concentrations of metals and nutrients in the two sludge plants and phyto-treated MSS in terms of compliance to food safety, fertilizer and landfill disposal standards.

2. Methods

2.1. Municipal sewage sludge and soils

Fresh municipal sewage sludge (MSS) was obtained from the Datansha Wastewater Treatment Plant, Guangzhou, China. It was dewatered by belt-filter and contained about 80% water. The major characteristics of the MSS and soils including heavy metals (Cu, Cd, Pb, and Zn), nutrients (N, P, and K), organic matter (OM), and pH are shown in Table 1.

2.2. Plants

Hybrid Giant Napier (*P. hydridum*) and *A. macrorrhiza* were obtained from the experimental farm of South China Agricultural University, Guangzhou, China. These two plants were previously grown in the university experimental farm by our group.

2.3. Experimental

2.3.1. Experiment 1.P. hydridum survival in MSS and soil-based media

The survival and growth of *P. hydridum* was tested on 4 medias: (i) soil (S, soil I in Table 1); (ii) fresh sludge (FS, Fresh MSS I in Table 1); (iii) soil-sludge mixture at ratio of 1:1 (v/v) (SoS); (iv) and phyto-treated sludge (PS) (Xu et al., 2015). Each treatment consists of a plot in the field measuring 2 m (length) by 1.5 m (width). For treatments that had MSS, the sludge was up to a thickness of 20 cm above the ground and separated by a plastic net in order to collect the treated sludge at the end of the experiment.

A total of 16 plants were planted in each plot with a 0.3 m line and 0.4 m column spacings. Out of the 16 plants, half of them (8 plants) were transplanted with ramets with roots, the other half (8 plants) was transplanted with stem cuttings. The ramets were cut shoots containing 12–15 cm stems with roots which were collected from plants grown in soil. The stem cuttings were cut to about 20 cm with 2 nodes without roots. The plants that survived were counted and harvested two months after the planting.

2.3.2. Experiment 2: growth of P. hydridum seedling incubated in peat-based medium in fresh MSS and soil

For growing *P. hydridum* in peat-based medium before transplanting, the following steps were conducted: plants stems were cut to about 15 cm (2 nodes), placed in plastic pots measuring 13 cm (diameter) by 11 cm (height) and filled with peat-based medium (Xuneng Biotechnology, Guangdong, China). One stem cut was planted into each pot, moistened with tap water and grown for 2 weeks.

The peat-based grown *P. hydridum* seedlings were then transplanted to be grown in fresh MSS II and soil II (Table 1). The MSS and soil was up to a thickness of 20 cm on the ground and separated by a plastic net in order to collect the treated sludge for analysis at the end of the experiment. The test was conducted in three replicates, with 12 seedlings transplanted for each replicate. After two months, the plants that survived were counted and harvested.

2.3.3. Experiment 3: comparison between P. hydridum and A. macrorrhiza

The experiment was conducted in an open field area covering 300 m^2. The area was separated into 8 plots with dimensions of 8 m (length) by 3 m (breadth). The plots were spaced 0.4 m apart from each other. After laying a plastic net for each plot, a 20 cm layer of fresh MSS III was applied. Four plots were planted with *P. hydridum*, similar manner to experiment 2. The other four plots were planted with *A. macrorrhiza* (with germinated tubers). Sixty-five plants were planted for each plot.

After a six month growth period without fertilization, the aboveground parts of *P. hydridum* and *A. macrorrhiza* were harvested and weighed. A sub-sample was washed three times with water; the final rinse was with deionized water. Plants were separated into stems and leaves and oven-dried at 65 °C for 72 h. The dried plant materials were grounded with stainless steel mill and passed through 0.25 mm sieve for elemental analysis. The plant tissue was digested in muffle furnace at 550 °C for 2 h. The ash was subsequently dissolved in nitric acid (1:1 v/v). Metal elements analysis was carried out by AAS (Hitachi Z-2300, Z-5300). Nitrogen

Table 1
Municipal sewage sludge (MSS) and soil characteristics.

	Fresh MSS I	Fresh MSS II	Fresh MSS III	Phyto-treated MSS	Soil I	Soil II	[a]Limits of pollutants in sludge for agricultural use	
							Class A	Class B
pH (Soil:water = 1:2.5)	[b]5.73 ± 0.12	5.53 ± 0.01	6.73 ± 0.06	6.09 ± 0.02	7.70 ± 0.10	6.49 ± 0.01	5.5–8.0	
Water content (g/kg)	833.4 ± 5.00	837.4 ± 1.90	795.0 ± 24.0	412.1 ± 1.50	233.3 ± 1.0	239.5 ± 1.20	⩽600	
OM (g/kg)	430.7 ± 13.7	447.6 ± 9.80	398.0 ± 5.20	334.5 ± 5.09	3.75 ± 0.41	2.37 ± 0.21	⩾200	
Total N (g/kg)	46.60 ± 1.48	56.52 ± 1.47	42.53 ± 0.81	28.36 ± 0.21	0.25 ± 0.13	0.30 ± 0.01	[c]$(N + P_2O_5 + K_2O) \geqslant$	
Total P (g/kg)	34.34 ± 0.18	20.24 ± 0.31	24.61 ± 0.33	40.09 ± 1.19	0.24 ± 0.01	0.21 ± 0.01	30	
Total K (g/kg)	6.88 ± 0.65	10.53 ± 0.07	11.42 ± 0.37	8.83 ± 0.00	7.22 ± 0.35	16.68 ± 0.41		
Total Cu (mg/kg)	389.9 ± 32.7	360.3 ± 1.9	194.3 ± 13.5	666.5 ± 14.3	17.43 ± 0.16	33.11 ± 0.84	500	1500
Total Zn (mg/kg)	1106 ± 52.2	1028 ± 8.9	788.3 ± 57.6	1532 ± 26.8	40.76 ± 6.04	33.79 ± 2.94	1500	3000
Total Pb (mg/kg)	64.41 ± 2.38	117.7 ± 0.4	97.45 ± 6.02	107.1 ± 6.91	46.76 ± 0.72	92.88 ± 1.66	300	1000
Total Cd (mg/kg)	4.43 ± 0.14	3.49 ± 0.06	2.65 ± 0.17	5.51 ± 0.23	0.11 ± 0.03	0.15 ± 0.04	3	15

[a] Limit values for agricultural use of sewage sludge according to the urban construction standard of the People's Republic of China (CJ/T 309-2009).
[b] All data values represent the means ± standard error ($n = 3$).
[c] $P_2O_5 = P \times 2.29$, $K_2O = K \times 1.20$, $(N + P_2O_5 + K_2O) \geqslant 30$ (g/kg, dry weight basis).