The co-treatment of mixed wetland plant and sludge by an earthworm reactor plant

Zheli Ding, Lina Han, Fei Lin, Zhaoxi Zhou, Xine Lin, Jianhong Ming , Bizun Wang *

Haikou Experimental Station, Chinese Academy of Tropical Agricultural Sciences (CATAS), Haikou, China;

* Correspondence to Prof Bizun Wang, Tel: 13876783004, E-mail: dingzheli@zju.edu.cn

Abstract

We selected earthworm *Eisenia foetida (Savigny)* to study the assimilation of wetland plant(M*yriophyllum aquaticum*) and sludge by earthworm reactor treatment, taken the method of grab sampling for observe the conversion efficiency, the result shows that: under the condition of sludge: *M.aquaticum*.=70%:30%, it takes the highest treatment efficiency, after 30 days treatment, earthworm increased 155%, treated products volume decreased 75.6%, available NPK takes greatly increased, OM (organic matter) increased 15.7%. This study gives a new point for wetland plant and sludge co-treatment, and proved to utilize earthworm reactor is suitable for sludge and wetland plants transforming, meanwhile, the treated products took good quality, which we can use for organic fertilizer application.

Keywords

Earthworm reactor; wetland plant; sludge; co-treatment;

1. **Introduction**

Constructed Wetland (CW) system has been intensively applied in waste water treatment in past decades due to its high contaminants' loading capability, high removal efficiency and self-cleaning ability (Kivaisi 2001; Brix *et al.* 2007; Puigagut *et al.* 2007). In a CW system, selected phytoremediation plants play the key role of removing contaminants by uptaking total nitrogen (TN), phosphate (P) as nutrients (Chen *et al.* 2006; Avsar *et al.* 2007; Ruiz-Rueda *et al.* 2010). However, how to harvest and recycle the wetland plants became an important topic because the non-appropriately harvested and disposed plants caused secondary pollution via nutrients release (Ghabbour *et al.* 2004). Currently, wetland plants were mainly used as raw Bio-energy materials though most of wetland plants are not suitable because of their high moisture percentage, for example, *M.aquaticum* has moisture content greater than 90% (Johnson *et al.* 1997; Delmail *et al.* 2011). High moisture content makes the dehydrating process costive.

Like wetland system, waste water treatment plant (WWTP) is another efficient water treatment manner, while also has its own disadvantage –large amount of sludge production. Sludge treatment counts 20% to 60% of the total operating cost of WWTPs (Wei *et al.* 2003; Andreoli *et al.* 2007). Besides, the traditional sludge treatments bring potential environmental or economic problems (Uggetti *et al.* 2010) A cost effective, environmental friendly method for sludge treatment is of great interest.

The earthworm technic, which is often called earthworm conversion, vermicomposting or vermistabilization, has been intensively studied for sludge treatment

(Hartenstein & Hartenstein 1981) since 1979, proved as an efficient low-cost mean for sludge treatment, and has been applied world widely.

In the vermicomposting (earthworm conversion) process, with the suitable earthworm species and well living condition, the worms can consume or metabolize the sludge into wormcasts, which can be used as soil conditioner. The earthworm can be further used for pharmaceutical industry (Wang *et al.* 2010a; Garg & Gupta 2011; Singh *et al.* 2011; Liu *et al.* 2012). However, there is limited study on wetland plant vermicomposting and its co-treatment with sewage sludge. In this study, we applied the earthworm reactor treating the mixture of sludge and wetland plant, to demonstrate the suitability of earthworm technical for wetland plant and sludge treatment from a technical, economic and environmental point of view.

2. Materials and Methods

2.1 Materials

Earthworm species: *Eisenia foetida (Savigny)* obtained from Yangzhou University. Earthworms were domesticated in greenhouse for more than 3 months.

Sewage sludge: Obtained from LinAn WWTP (properties shows in table 1). A separate constructed wetland plant was connected with the WWTP to purify the tail water. Sludge sample was stored in dark at room temperature for 5 days before using.

Table 1 property for text materials

Text materials	TN (g/kg)	Available N concentration(mg/kg)	TP (g/kg)	Available P concentration(mg/kg)	TK (g/kg)	Available K concentration(mg/kg)	C/N	Water content (%)
M.*spicatum*	21.8	-	0.9	-	22.4	-	34.8	89.6
Sewage sludge	23.8	1576	17.8	1432	5.3	351	14.5	82.8

Wetland plant: *M. spicatum* L, obtained from LinAn WWTP. The crumbs were made by smashing *M. spicatum* L into particulars (OD<5 mm), then naturally dried outside for 2 days.

2.2 Experimental set up

We constructed an aphytotron at Zijingang Campus at ZheJiang University, and carried out the experiment more than 30 days. We mixed the sludge and crumbs of *M. spicatum* into each plastic pot (sides =5×11cm R×H) at different volume ratios: 100:0 (100% sludge), 80:20 (80% sludge), 70:30 (70% sludge), 60:40 (60% sludge), 50:50 (50% sludge), all sets were performed in triplicate. 20 middle size earthworms were selected and put into each pot (Callaham *et al.* 2009). We took the samples at day 0, 10, 20, and 30, stored the samples into plastic bags at 4 ^{o}C for further analysis.

2.3 Methods

After 30 days, the earthworms were separated carefully and counted manually. We analyzed the compound volume changes by comparing the volumes of the plastic pots at the beginning and the end of the experiment. We measured OM by subtraction method, We measured TN using alkaline method. Measured TP using UV spectrophotometry, measured TK using flame atomic absorption spectrophotometry determined. The available N was measured by hydrolysis method, available P was measured by UV spectrophotometry method after $NaHCO_3$ extraction, available K was measured by flame atomic absorption spectrophotometry after NH_4OA extraction. We measured the heavy metals by ICP-MS after HNO_3-$HClO_3$-HF digestion. All the analyze method were referred to soil and agricultural chemistry analysis(Bao 2000), and the samples were air dried at room temperature to reach a constant weight before measuring. All data were expressed on a dry matter basis (Chiu *et al.* 2006).

2.4 Data analysis

The data were analyzed through one-way analysis of variance (ANOVA) detect the statistical significance of differences ($p \leq 0.05$) between means of treatments, the Tukey test was performed(Whiteman *et al.* 2010). Pearson correlation coefficients were calculated using SPSS 16.0 and used EXCEL for figures.

3. Results and Discussion

3.1 Effect of sludge and *M. spicatum* composing ratios for earthworm growing

Figure 1 shows the earthworm numbers in plastic pots with different sludge and *M. Spicatum* L composing ratios after 30 days treatment. Earth worms grew best under the condition with 70% sludge, in which the earthworm number increased 55%. Earthworm numbers increased 33%, 17%, and 8% for the treatment with 80%, 60% and 50% sludge, respectively. For the treatment with 100% sludge, it slightly decreased to 87% of the input. The alive earthworm number was significantly affected by the ratios of sludge and plant crumbs of each treatment, clearly the treatment with 70% of sludge had the highest earthworm numbers after 30 day. This might because adding extra of plant crumbs fasted the air exchange, enhanced the oxygen concentration of the sludge by loosing the inside space, thus improved the living condition for the earthworm, while the decayed plant crumbs might also play the role as food (Spiers *et al.* 1986) for earthworms. However, too much *M. spicatum* addition probably increased the moisture content, and resulting in decomposition of the mixture way much harder, which will negatively affect the living condition for earthworm.

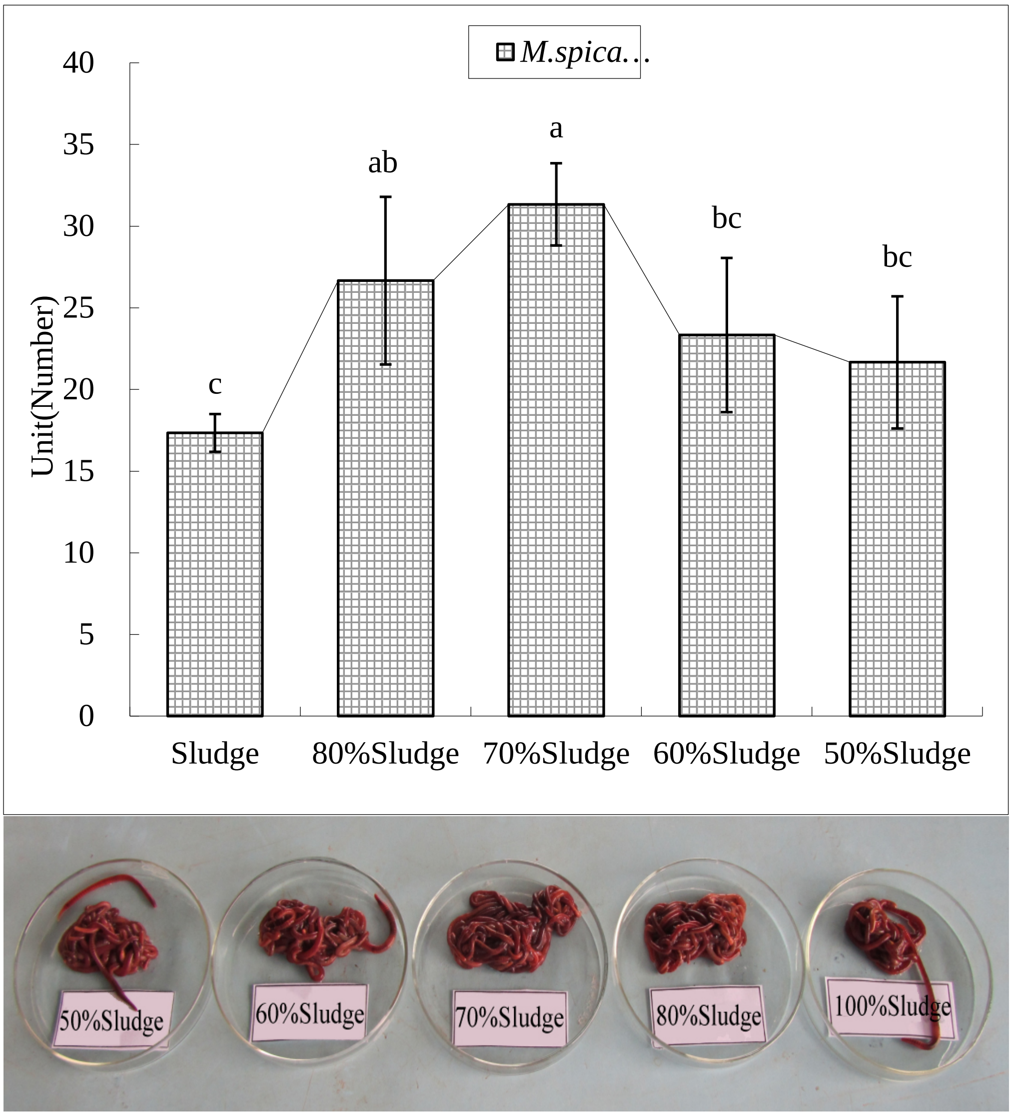

Figure 1 E. *foetida* number after 30 days treatment

The earthworm grew differently under different conditions with varying ratio of sludge and *M. spicatum* crumbs. This might be caused by different ratio of C: N of each treatment. The most suitable ratios of C:N for earthworm is about 20~25:1 (Gupta & Garg 2010; Vig *et al.* 2011; Gao *et al.* 2012), while usually the C:N ratio of pure sludge is less than 15:1 (Zhao *et al.* 2011; Dai *et al.* 2012). Adding the crumbs of *M. spicatum* obviously increased the C:N ratio of the mixtures. The C:N ratios were regulated to about 19:1, 21:1, 23:1, and 25:1 for the mixtures with 80%, 70%, 60%, and

50% of sludge treatment respectively, clearly more suitable conditions for earthworm lives than pure sludge.

3.2 Compounds volume changes under earthworm reactor treatment

Figure 2 shows the volume changes of each set after treatment. The volumes of all tested sets significantly decreased. The volume reductions were more than 60% for all experimental sets, volume reduced 72%, 67%, and 65% for the pots with 60%, 80% and 50% sludge treatment, while the volume decreased 76% for the pot with 70% sludge treatment. The main reason for compounds volume change is made of dehydrate and organic matter composition. Uggetti (Uggetti *et al.* 2010) reported the main mechanism for sludge reduction is contributed by dehydrate. Water in sludge is constituted as pore water (67%), capillary water (25%), adsorbed and structurally bound water (8 %), in this study, the water content of pure sludge is 83%. For pore water, capillary water, and the organic matter which are hardly removed by normal physic method but could be utilized by earthworm, thus can be transferred to autologous nutrients or volatilize into the air by respiration.

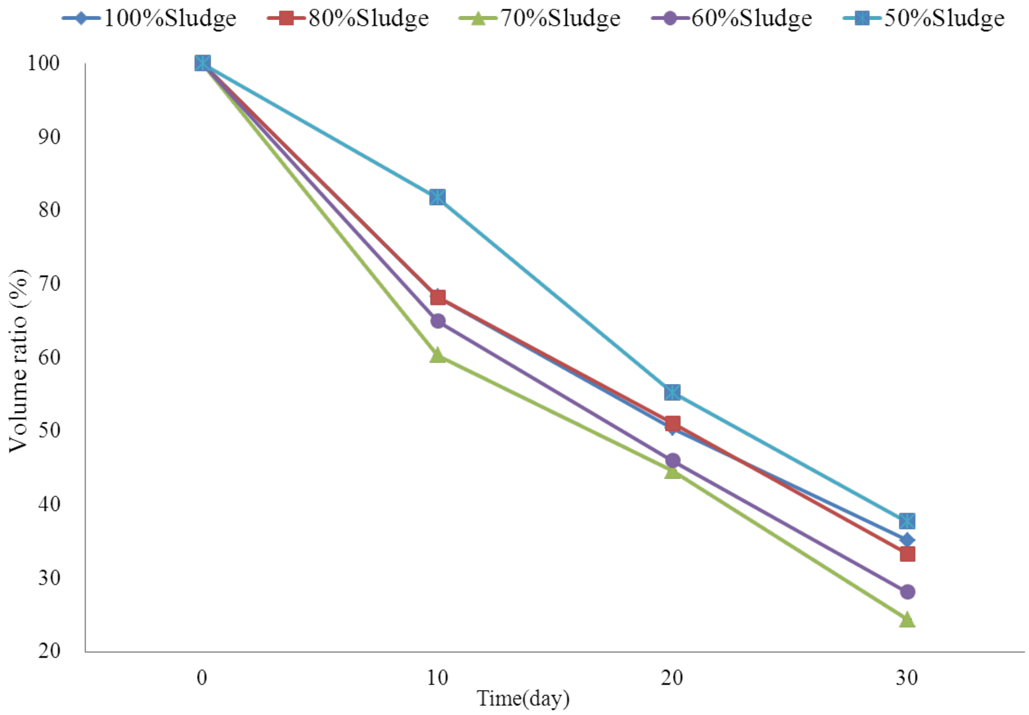

Figure 2 Compounds volume changes followed with time variation

Through correlation analysis between the volume changes and earthworm number conditions (r=0.737), we found that the final volumes were significantly related with lived earthworm numbers, the higher earthworm number, the higher volume reduction rate. This is reasonable while volume reduction may cause by the effect of earthworm activity, which can increase the air exchange, and enrich large amount of microbes. The growth of earthworm and microbes need to consume nutrients and other materials, thus decreased the volume of the products. There is few research on earthworm numbers to vermicomposting products volume changes, but many authors(Vesilind 1994; Zhang *et al.* 2009; Wang *et al.* 2010b) thought the treatment for sludge volume changes is caused by water and organic matter consuming, which is also thought to be the most important reason for our reactors treatment. After treating, Water was consumed by earthworm to accomplish its active, and some part of water and OM were exchange into the air, meanwhile, the microbe in this reactor also need it for active, which lead to the compound volume greatly changes.

3.3 Effect of earthworm living condition for nutrients transfer

Table 2 summarizes the NPK concentration changes through the treatment. Clearly, TNPK concentrations was remarkable increased after treatment. For TN and TP, the increasing rate is not high, but for TK, it increased 5.06, 9.35, 13.24, 12.37, 13.75 mg/kg for each treatment separately, meanwhile, 100% sludge treatment got the lowest increasing rate. Plant K the main reason for K transforming into the treated products, in this study, TK for M.*spicatum* is 22.4 g/kg, which is much higher than K content in sludge, by the active of earthworms and microbe, earthworm reactor can biological mineralization the decayed plant, which improved the K concentration for treated products. The available N, K increased 160 and 266 mg/kg for 70% sludge treatment respectively, which took the highest increasing rates in all. For available P, it got increased for each treatment, but not significantly. With the active of earthworms, it greatly increased the available nutrients for each treatment, and the reasons are thought to be:

1. Earthworm improved the permeability of the mixture, while correspondingly promoted the microbe reproduction, thus enhanced the bioavailability of nutrients through decomposition, mineralization and migration.

Table 2 NPK variation by different sludge ratio treatment

Treatments	TN concentration(g/kg)	Available N concentration(mg/kg)	TP concentration(g/kg)	Available P concentration(mg/kg)	TK concentration(g/kg)	Available K concentration(mg/kg)
100% sludge	24.78±5.06	1542±97	19.45±0.03	1473±41	10.36±1.25	463±7
80% sludge	24.87±0.72	1653±112	19.76±0.01	1521±67	14.65±0.08	578±38
70% sludge	26.83±5.09	1736±224	19.71±0.05	1497±117	18.54±6.48	621±39
60% sludge	25.98±1.14	1627±80	19.59±0.15	1511±165	17.67±4.96	563±84
50% sludge	26.21±4.54	1574±56	19.36±0.09	1496±39	19.05±5.92	536±58

Notes: mean values as X±SD. Within 3 mean values of each character, there is no significant difference between those containing same letters, and there is significant difference between those containing different letters.

2. N, P, and K nutrients were mainly transformed from *M. spicatum* and sludge to wormcast by *E. foetida* active. Through the metabolic activities of *E. foetida*, nutrients were transformed from the difficult macromolecule substance into micromolecule(Bhartiya & Singh 2012), making N, P, K, and other nutrients more bioavailable to be utilized.

3. Though digestion, *E. foetida* excrete the microbes (including the nitrogen fixers) in the mixture along with nutrients nitrogen (N) and phosphorus (P) (Boyer & Wratten 2010). The functional enzymes also promote nutrients transferring by synergistic effect.

3.4 Effects of OM and heavy metal content on earthworm reactor performance

Table 3 Organic matter content in treating（%）

Treatment	100% Sludge	80% Sludge	70% Sludge	60% Sludge	50% Sludge
Before treating	31.54±1.65	32.68±5.98	35.7±1.73	34.54±1.89	37.87±1.78
After treating	35.24±3.70	37.84±1.44	41.4±1.11	41.17±3.15	40.28±1.94

An increase of OM content can improve the physical properties (water retention, soil structure, water infiltration, bulk density, porosity), chemical properties (cation exchange capacity, pH), and the biological properties of the mixture(Singh & Agrawal 2008). For this study, the OM content of each treatment increased obviously. For 70% sludge treatment, which had the highest earthworm number, the OM content changed from 36% to 42% (table 3). The increasing OM may cause by transformation of inorganic carbon, the decayed plants were broken down in digestion by earthworm, and further mineralized by microorganisms. From other reports, OM was always decreased by vermicomposting process, which was not the same as our results, but there was little plant addition in other studies. From our result, the plant addition is the key point for

OM increasing, with the active of earthworm reactor, it can transferred into OM from the decayed plant.

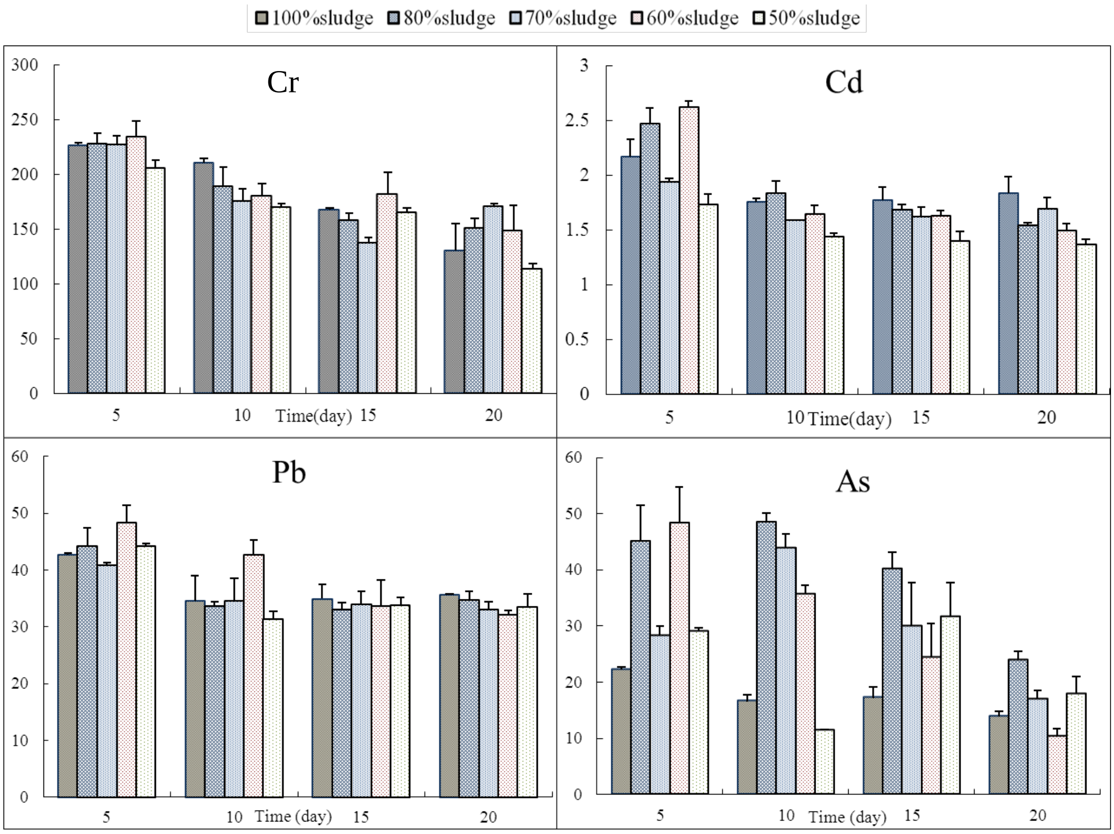

Figure 3 Cr, Cd, Pb, As (mg/kg) contend changes by earthworm reactor treatment

The main hazard associated with this application is the potential long term accumulation of toxic elements. However, because of the low concentration in the influent(Wei *et al.* 2011), heavy metals concentrations for sludge and *M. spicatum* were clearly below the law thresholds, which did not take any harmful effect on earthworm grows or treatment products quality. After treatment, heavy metal content was little decreased between the compounds and the final product, suggesting that heavy metals accumulation in wormcast was negligible(Voua Otomo *et al.* 2011). For 70% sludge treatment, Cd, Cr, Pb, As decreased 17%, 25%, 19% and 40% respectively, the decreasing of heavy metals may cause by the enzymes effect or grumes in earthworm body surface(Maenpaa *et al*. 2002; Dai *et al*. 2004; Liu *et al*. 2005), it can affect the activate or chelation for heavy metals, which lead to metal ions inactivated, meanwhile, metal enrichment in earthworm body maybe the other reason for metal decreased, from others studies, heavy metals can be accumulated in its body, which lead to reduce the ecological risk of the treated products. But heavy metal content is not detected in this study, which is still need for further studying.

4. **Conclusions**

This study looked at technical and environmental aspects of earthworm technical for sludge and *M. spicatum* co-treatment, the effect was then analyzed, with the treatment of sludge: *M. spicatum*= 70%:30%, the earthworm reactor got the best transforming effects, which the treatment products got the largest volume reduction, available nutrients and OM increased, and the treatment products can be used for ecological matrix or organic fertilizer. With the result of our research, heavy metals didn't show harmful for earthworm lives, meanwhile, *E. foetida* active was finding to passivate or decrease the metal concentration of the treated products.

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