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Metal partitioning and relationships to soil microbial properties of submerged paddy soil contaminated by electronic waste recycling

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Metal partitioning and relationships to soil microbial properties of submerged paddy soil contaminated by electronic waste recycling

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Th n r on w n ro ro r n r on n wr n n o r n h on of r n fi x r n . S from n ron w -r n n r (-w n r) wr h on n . M r r on n ho w h of o n n h n n of ro h o o ro wr ff r C , r Zn, x h n C , x h n Zn n F Mn-ox n C . Th r C on n r on o r 66.7, 35.5 n 62.4% of h r n n h of f r , rox n r , r , w h on n r on of x h n C , x h n Zn n F Mn-ox n C x n 43.2, 9.9 n 65.2% of h r n n , f r n ho h , r . Th on n of r C n r Zn o r 89.0 n 42.7%, r , of h r on n h n n of o r n -r n r . Ho w r, r on n w ff o roor n . Or n Zn n F Mn-ox n C wr ff o r n f r-ox n r . Th n n of o r x n 69.8 n 64.7% of h r n n or n Zn n F Mn-ox n C , n f r-ox n r x n 21.0% of h r n n F Mn-ox n C .

Keywords: - w ; r on n ; o ; o n ; o roor n

1. Introduction

I ro r ron w (- w) ro n ro n ro hro h w h ox - n n o h n ron n . 1 Th on of h , o ro h ro r on (PAH), o h or n h n (PCB) n o ro n h n h r (PBDE) n o , n , 2,3 r 4 n foo 5,6 r of on - r ro r - w r n h n r or n n r . Th r n of on n n r n n h n o h n n n of h o n n f n on r o ro o n . Th , h r n of o n n o h n n h o o n r r . 7,8 Ho w r, h ff of ro r - w r n on o n n roor n h n r r , n r fi on on .

I h n ro o h o n n roor n r n or of h of o of n on n r o r f r n r (r n n r n). A ho h n o n n r o n 9,10 or h n h o o n r r , 11 h ox of o n x r , r r n r on o ro , h r h r n on. In on, o

*Corr on n hor. E : h n j nh @ . n

wh or no on r on for hm r on n n o . How r, on n x on rn n h m or n of o n m r on n n r m ox . H r , w fo on h ox n o of m x r of m n h m r o rro n n n - w r n r .

So m roor n m n nfl n h mo n o of m hro h r of ro . 12 Th n no on n r h n n h h n h m ro r of h o , o r n m on on h om o n , wh h r rm n ron or , n h n h of m o wh h . 13 Th , h of o m roor n m m h n r ff on h m fr on on/ r on n rn. How r, h r r f wr or rr n n h h r r on h j . In h , wo o on mn - w ro n n on on ro o wr . M r on n , o n m n h n n of m ro h o o ro wr on n o mn r n on of h r ro . A f r h r m w o h m r r on h w n m r on n n h o n h r m ro ro r n m n r r r on n . Th r on h wr h n o n h n r on of h m ro ro r n h m r on n .

2. Materials and methods

2.1. *Research area*

Th r r h w on n o - w n r (28°29′ N, 121°20′ E) o n h o h of Zh j n ro n , Ch n (F r 1). Th r h n for - w ro n for o r 20 r . Th r on h nor h rn - ro mon oon m . Th m n nn r on 1600 1700 mm, of wh h 60.2% r w n M n S m r. Th nn m n r m r r 17°C, wh m x m m of 40.8°C, n m n m m of −9.9°C.

2.2. *Experimental set-up*

In J 2006, wo (G1 n G2) n h - w ro n n r n on on ro (CK) wr ho n for (F r 1), h n hr r n om r o of 5 m × 4 m. G1 w o n r w w r o f from n - w ro n f or . G2 w o n r m n wh h r mo n of n m r w . CK

F r 1. M ho wn h r . Th wo wr o n n - w r n n r . CK n o . Th m of T ho from L n 45 .

w o 120 m from h r n n r . P r n (*Oryza sativa* L, IE OU 9308) wr r n n n ro w 20 m r . E h h on n hr n (21 o), wh h wr h n n of 15 m A o wr n r m floo on on for 105 , n wr r n rox m w for h r . P n n r n wr hr m (h n , r or o r n n n n flor n) n h for m of r (50 h $^{-1}$). B o m wr o 0, 15, 20, 50 n 80 f r r n n n . Th fi m n m wr orr on o r or o r n n n , r , m , flor n n m r of h r o m n , r . For h m n , fi m r o wr r n o m o h of 15 m w h h n - r n ho n h n m x o on n m r o . Th m wr o < 2 m m n or n n o h n 4°C n n .

Ch m n wr rfor m on r o m . P o- o m on n r on n h o m wr r m n f r on w h o m n on of on n r HNO_3 n $HC O_4$. Th C , Zn n C n h o m wr n x r , fo o wn h m ho of T r, [14] n o fi h , n wr o r on fin h x h n , r on- , F Mn-ox n , or n n r fr on . Th m on n of h o on wr r m n n o m o m m on ro m r (ICP-OES, O m 2100 DV, P r n E m r, USA). Th r o r r fro m h m of h fi fr on o r h o r m on n r on , r m n n o' o on, r n w n 75 n 110%. Th o H w m r n H m r w h 1 : 2.5 o / w r n on. [15] Th o or n m r w r m n h w o m on m ho of nor m. [16] Th o o n ro n (TN), o o ho horo (TP) n on- x h n (CEC) of o m wr r m n or n o Br m n r n M n . [17] C w r m n or n o R. O h n r. [18]

Th o n m n h n n of o m roor n m wr m r n fr h w m . C w n n o m r m n n r on. [19] P rox w n n ro o r . [20] Th r n h o m wr m r h o h r n for m on of r n o m m on m [21] S f r w r m n h EDTA r on m ho . [22] In r w n n ro h r . [23] A ho h w r m n h r n on of *p*-n ro h no (PNP), n 0.1 M h n - ho h o m r . [24] Th n n of m m on ox r, n r fi r, f -r n r (SRB) n f r-ox n r (SOB) wr r m n h m o ro n m r (MPN) hn . Th n n of o ro or f n ro r (o r) n m -r n r wr o n h o r m ho . Th for m r wr x o n h o m ro o m m n o fin m n r m m, [25] wh h r wr x o n h o m m w h 2 m M P $(NO_3)_2$. A wr r or on n o n r .

A x r m n r r or h m n ± n r on . Th wr n on - w n of r n (ANOVA) n m w r r on , n S P for h So S n (SPSS) 11.5 for W n o w. M o m r on wr h ANOVA n T ' . Th n fi n ff r n (LSD) m on m n wr $p < 0.05$.

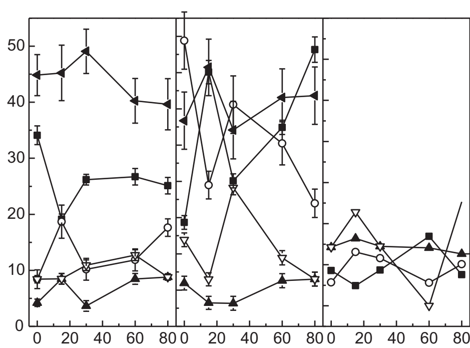
3. Results

3.1. *Soil physicochemical properties*

Th o ff r r n h r H n r m on n (T 1). So G1 n G2 wr , wh r n r n r H w fo n for h on ro o . Th o or n m r, T 1. Ph o hm ro r n m on n r on of h o m n from h - w on m n o n h on ro (m n ± SE).

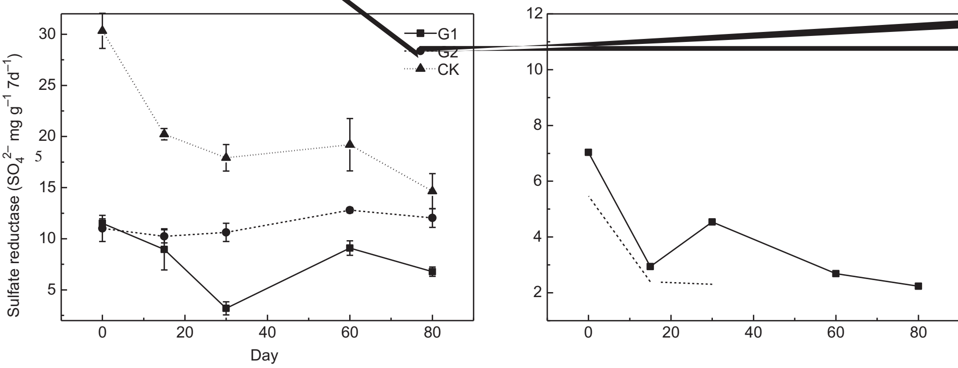
	G1	G2	CK	En ronm n n r for o (Ch n , Gr II, H < 6.5)
H	4.49 ± 0.08	4.40 ± 0.23	6.08 ± 0.04	
Or n m r ($^{-1}$)	58.43 ± 4.72	44.30 ± 4.07	57.67 ± 3.58	
To N (m $^{-1}$)	2,230.00 ± 137.00	2,730.00 ± 179.00	2,390.00 ± 157.70	
To P (m $^{-1}$)	332.81 ± 17.71	419.68 ± 20.19	425.00 ± 18.74	
CEC (mo 100 $^{-1}$)	3.703 ± 0.44	5.477 ± 0.47	5.600 ± 0.23	
C (%)	7.62 ± 0.98	8.40 ± 1.18	8.12 ± 0.79	
C (m $^{-1}$)	6.39 ± 0.30	16.04 ± 0.68	0.15 ± 0.03	0.3
Co (m $^{-1}$)	63.34 ± 1.38	76.08 ± 1.87	8.72 ± 2.43	
Cr (m $^{-1}$)	18.58 ± 0.88	30.54 ± 0.69	6.33 ± 1.03	300
C (m $^{-1}$)	298.64 ± 37.06	406.62 ± 40.21	32.08 ± 2.11	100
F (m $^{-1}$)	33,882.00 ± 894.23	35,574.69 ± 907.18	15,598.68 ± 1046.56	
Mn (m $^{-1}$)	369.47 ± 30.12	345.39 ± 28.40	324.81 ± 24.66	
P (m $^{-1}$)	36.22 ± 2.17	46.70 ± 2.93	33.44 ± 1.33	250
Zn (m $^{-1}$)	205.70 ± 40.88	255.75 ± 43.67	111.99 ± 37.77	200

TN, TP n on n n h hr o m wr rox m n, wh r h CEC of o G1 w 32.39 n 33.87% o wr h n ho of G2 n CK, r , n n h o G1 h n ffi n ff r n for m on m n on.



Th o of G1 n G2 wr n fi n nr h wh r u , wh ff r n n h F Mn-ox n , r on n x h n fr on of C n o G1 n G2 wr h h r h n ho of CK. Th r on n wh r o . L o oo r n n r of F Mn-ox n - o n C n w w r- rr o . 29 L r r on n C fr on on wr o r , for h non-r fr on. Ho w r, no on n h n wr o r uon h hr o . A h h ro or on of h x h n n r on fr on wr o r G1 n G2. Cou r n wh h r fr on of C n Zn, h r n of r C w r o wr n n from 39.64 o 45.23%, 27.07 o 35.71% n 42.78 o 63.38% for o G1, G2 n CK, r .

M w r r on wr o h n fi n r nfl n n h u r on n n h o of h floo , n o h n on. A ho w n T 2, uo of h on h h h r wh h h R^2 . Th n h h u r on n rn n h o wr n n u r u h n o uo fi hr r u r . Th fir w h n r on w n ff r n u fr on ,



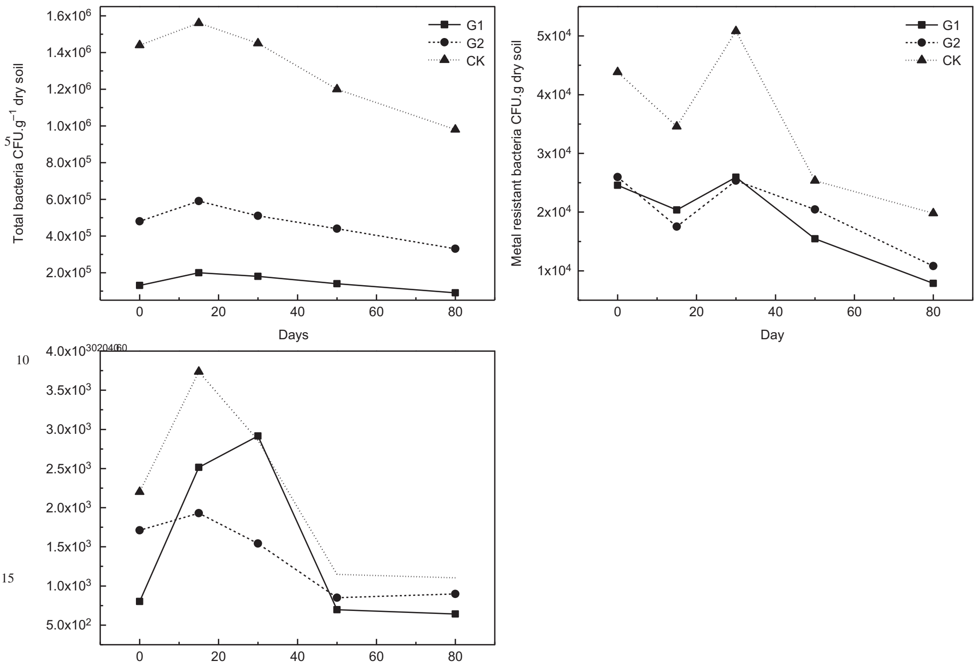
T 3. Corr on o ffi n (r) for r on h w n o ro r n h on n n ff r n fr on of h o ($n = 45$, 3 × 3 o × 5).

	Zn_{F1}	Zn_{F2}	Zn_{F3}	Zn_{F4}	Zn_{F5}	C_{F1}	C_{F2}	C_{F3}	C_{F4}	C_{F5}	C_{F1}	C_{F2}	C_{F3}	C_{F4}	C_{F5}
S f r	−0.817**	−0.331	0.282	−0.289	−0.701**	−0.708**	−0.628*	−0.633*	−0.398	−0.534*	−0.633*	−0.432	−0.402	−0.492	−0.806**
In r	−0.329	−0.195	−0.079	−0.420	−0.483	−0.154	−0.441	−0.419	−0.229	−0.286	−0.209	−0.335	−0.221	−0.351	−0.367
C	−0.467	−0.293	−0.233	−0.479	−0.645**	−0.657**	−0.574*	−0.541*	−0.347	−0.469	−0.462	−0.391	−0.395	−0.372	−0.639*
P rox	−0.522*	−0.174	−0.284	−0.259	−0.596*	−0.553*	−0.458	−0.410	−0.577*	−0.379	−0.490	−0.246	−0.335	−0.384	−0.599*
Ur	−0.598**	−0.409	−0.385	−0.437	−0.772**	−0.787**	−0.707**	−0.758**	−0.428	−0.745**	−0.756**	−0.563*	−0.502	−0.503	−0.790**
A h o h	−0.378	−0.381	−0.522*	−0.207	−0.528*	−0.434	−0.517*	−0.451	−0.634*	−0.408	−0.386	−0.344	−0.808**	−0.214	−0.329
To r	−0.783**	−0.331	−0.015	−0.328	−0.871**	−0.872**	−0.705**	−0.736**	−0.431	−0.646**	−0.761**	−0.460	−0.584*	−0.458	−0.906**
M -r n r	−0.592*	−0.421	−0.019	−0.359	−0.653**	−0.519*	−0.644**	−0.557*	−0.584*	−0.460	−0.436	−0.437	−0.594*	−0.387	−0.539*
A on ox r	−0.235	−0.149	−0.019	−0.365	−0.396	−0.475	−0.326	−0.355	−0.371	−0.407	−0.430	−0.215	−0.426	−0.097	−0.286
D n r fi r	−0.109	−0.052	0.363	−0.197	0.232	−0.072	0.054	−0.047	−0.352	−0.061	−0.073	0.009	0.025	−0.167	0.129
S f r-ox n r	−0.329	−0.006	−0.038	−0.135	−0.435	−0.449	−0.242	−0.250	−0.254	0.028	−0.159	0.047	−0.506	−0.004	−0.511
S f r-r n r	−0.366	−0.257	0.468	−0.124	−0.052	−0.096	−0.223	−0.215	−0.275	−0.235	−0.205	−0.243	−0.125	−0.238	−0.089

No : **Corr on n fi n h 0.01 (w- , $n = 45$).
*Corr on n fi n h 0.05 (w- $n = 45$). F1, x h n fr on; F2, r on fr on; F3, F Mn ox n fr on; F4, or n fr on; F5, r fr on.

T 4. D fro r r on n n ro ro r , o h o h h r r n on n r on n ff r n for ($n = 45$, 3 × 3 o × 5).

En o n	M n rr r on	S
S f r	$= 17.738 - 0.150$ Zn x h n $- 4.263$ C r	$R^2 = 0.766, p < 0.001$
In r	A r r r o	
C	$= 0.113 - 0.003$ C x h n	$R^2 = 0.432, p = 0.008$
P rox	$= 38.740 - 0.024$ C r	$R^2 = 0.355, p < 0.019$
Ur	$= 0.625 - 0.105$ C r $+ 0.001$ N	$R^2 = 0.756, p < 0.001$
A h o h	$= 2.062 - 0.927$ C F −Mn ox n	$R^2 = 0.652, p < 0.001$
To r	$= 1,729,902.3 - 651,583.6$ C r	$R^2 = 0.890, p < 0.001$
M -r n r	$= 61,741.2 - 38.6$ Zn	


Total bacteria CFU.g−1 dry soil
1.6x10^6
1.4x10^6
1.2x10^6
1.0x10^6
8.0x10^5
6.0x10^5
4.0x10^5
2.0x10^5
G1
G2
CK
0
20
40
60
80
Days
Metal resistant bacteria CFU.g dry soil
5x10^4
4x10^4
3x10^4
2x10^4
1x10^4
G1
G2
CK
0
20
40
60
80
Day
4.0x10^3
3.5x10^3
3.0x10^3
2.5x10^3
2.0x10^3
1.5x10^3
1.0x10^3
5.0x10^2
0
20
40
60
80

n o . A ho h ox n w ro r n h m ox on r on n mo r on of h r o f r floo n , 33 m n ro r r m n n h o . O r , h n m r of o r r fro m on 0.9×10^4 o 9.8×10^5 r of r o . Th n n of o r n o G1 n G2 r n n m r o on or r of m n o wr h n ho of CK. Th n n of o r w n fi n orr w h h on n of x h n Zn ($p < 0.01$), r Zn ($p < 0.01$), x h n C ($p < 0.01$), r on C ($p < 0.01$), F Mn-ox n C ($p < 0.01$), r C ($p < 0.01$), x h n C ($p < 0.01$), F Mn-ox n C ($p < 0.05$) n r C ($p < 0.05$). Ho w r, on h r C n n o n h on, x n n ∼89.0% of h r on n h n n of o r (T 4) m n n h h r on n o r w m n o h m on of r C . So fro m h on ro h h h h n n of m -r n r r or o r n n n , wh r h n n of m -r n r n G1 n o G2 wr n r . Th n n of m - r n r w n fi n orr w h h on n of x h n Zn ($p < 0.05$), r Zn ($p < 0.01$), x h n C ($p < 0.05$), r on C ($p < 0.01$), F Mn-ox n C ($p < 0.01$), or n C ($p < 0.01$), F Mn-ox n C ($p < 0.01$) n r C ($p < 0.01$). Ho w r, on r Zn n n ro n o h on, x n n 42.7% of h r on n h n n of m -r n r . Th n n of m m on ox r fl w n 643 n 2915, 850 n 1929, n 1105 n 3738 r of r o for o G1, G2 n CK, r . Th n n of n r f n r n h o fl w n 40 n 450 r of r o , w h m x m m of 3738 r of r o (CK, 15), n m n m m of 643 r of r o (G1, 80). Ho w r, n h r m m on ox r nor n r f n r wr n fi n orr w h m on n . Lo w n n of SOB n SRB wr o r n o . Th SOB r n fro m 10,000 o 33,000 r of r o , wh r h SRB r n fro m 18 o 14,634 r of r o . N h r SOB nor SRB w n fi n orr w h m on n (T 3).

4. Discussion

Th on - r m, m ro r r n of - w h no on r n m m on n h o , h o mo fi h m r on n rn. Th , h m on of m m h r ff on h o o m Lo wr o n m n m roor n m n n wr o r n h o o wh n o m r w h h on ro , wh h m h on r o h m on of o n n h r on of o . O r r ho w h f r , r , ho h n o r wr h h n o h m on of r m n h o . In r w no n o r m m on n h - w on m n o , ho h h r o n r or n mor n o m on m n on h n n ho h n o on m n w h n m . 34 Th ff m on r o h n r on of ff r n o n . 9 Th on n of x h n Zn, x h n C , F Mn-ox n C , r Zn n r C wr r m r h ff h o m ro ro r o h r x n , o h m n h x h n (o) fr on n h r on fr on n h h mo . M n h for m x r ron nh or ff on o m ro n o h m r m r . 35 Ho w r, m o w h h F Mn ox ho w n r m mo . Ch n n h r ox on on m h r of m , o m m r r n o f h r r n n fi m n r . 36 A ho h m n h r fr on , m n m or n ro oo o r n h m n h o o on, r r C . A h mo mo n o n o m , C r m r n non- r r on m n r , or n m r, n F Mn ox m n r . 37

So roor n o ro n h or on n of o . So ro ro , n n o ro h n h ro ro h h n h n , r r on, f r on n fi r on, n r fi on n n r fi on 38 n fi n nfl - n . 12,39 F r h r or , r n hro h or on r . 40 Ho r, h ff r r o non-r fr on , for or n r- o n Zn n F Mn ox - o n C . Th r on n h h r r h of B rro 41 n H on ., 42 o h ro - r on n n o n o n n r n or n o n . Th on r o h or on of o roor n o on . D on on nor fr on of h o o n h o , h r nor rf r h on r- r of h o . 43,44 In on, h r ox n on on o ro or f n ro r o n h r r of Eh n h floo o , n n h on n on n on of r n on on. Un r r n on on, C o- r h fi - on n n o or r - or on on r ron fi r , h n r n h fr on of F Mn-ox n C . Th o n h C or n h n Zn o Eh h n n n h o .

Non h , fi on of h o h r fr on of r o roor n r , onfir h r o on r on o h r n . On o x n on h ro h o o ro r n o r n ron n f or , h n , h r n n r ff r n n r h fi on on . F r h r or , h ff of roor n r r o h ro n ron n . Ho r, h ff h n o r o h n h n n h o h o h h r r of h o .

To o r no , h h fir n- h n n h h fr on on/ r on n of C , Zn n C n h r r on h h o ro ro r n o on n ro r - r n .

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Th r or h N on N r S n Fo n on of Ch n (21107079), S n fi R r h F n of Zh j n Pro n E on D r n (201016193) n N hoo T n ro r of Zh j n Pro n (2013R428013).

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