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Abstract, tables and figures

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Fate and effect of zinc from tyre debris in soil

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Abstract

Tyre debris contains significant quantities of zinc (Zn) and there is concern about the diffuse Zn contamination of soils from tyre wear. An experiment was set-up to quantify the fate and effect of Zn from tyre debris in soil. Two different soils were mixed with the <100-µm fraction of car and truck tyre debris (25 g kg^{-1} soil) or zinc sulphate ($ZnSO_4$) as a reference. Soils were transferred to soil columns with free drainage and placed outdoors for 11 months. Leachates of the tyre debris amended soils did not contain significantly (P>0.05) more Zn than control soils except for a 3-fold increase in one soil amended with car tyre debris. The increase in Zn leaching due to tyre debris was only 3 % of the corresponding increase in the $ZnSO_4$ treatment at the same total Zn in soil. Tyre debris application increased the soil nitrification potential whereas $ZnSO_4$ application, at corresponding or smaller total Zn concentration, decreased nitrification potential. An increase in soil pH was observed in all soils treated with tyre debris and explains the increased nitrification potential. About 10-40 % of the Zn from tyre debris was isotopically exchangeable in soil sampled after 1 year weathering. It is concluded that a significant fraction of Zn is released from the rubber matrix within 1 year but the parallel increase in soil pH limits the mobilisation of Zn in soil.

Synopsis: Tyre wear is a significant source of zinc in roadside soils but only minor mobilisation of Zn was found in soils amended with finely ground tyre rubber.

Table 1. Selected characteristics of the non-contaminated soils.

	soil B	**soil T**
Texture	Sandy	silt loam
% clay	2	17
% silt	8	72
% sand	90	11
Organic carbon (%)	2.1	0.9
CEC (pH 7) $cmol_c\ kg^{-1}$	6.8	10.2
pH ($CaCl_2$ 0.01 M)[§]	4.9	6.1
Aqua regia soluble metals		
Zn ($mg\ kg^{-1}$)	26	37
Cd ($mg\ kg^{-1}$)	0.4	0.4

[§] in control samples 8 month after the start of the experiment

Table 2. Zn concentrations (mg L^{-1}) in membrane filtered soil solutions. Means followed by same character within columns are not significantly different at $\alpha<0.05$.

Treatment	soil B (acid sand)					soil T (silt loam)				
	09-Nov-99	13-Dec-99	28-Feb-00	28-Jun-00	06-Oct-00	09-Nov-99	13-Dec-99	28-Feb-00	28-Jun-00	06-Oct-00
control	0.51^{d}	0.28^{e}	0.11^{f}	0.25^{c}	$0.34^{c,d}$	0.11^{b}	0.17^{c}	$0.04^{b,c}$	0.03^{c}	0.01^{c}
truck tyre	0.31^{e}	$0.50^{d,e}$	0.22^{d}	0.16^{c}	0.19^{d}	0.13^{b}	0.11^{c}	0.02^{c}	0.03^{c}	$0.01^{b,c}$
car tyre	3.3^{c}	1.0^{c}	0.70^{b}	1.6^{b}	$0.88^{b,c}$	0.17^{b}	0.11^{c}	0.07^{b}	0.05^{c}	0.03^{b}
ZnO	14.8^{b}	4.5^{b}	2.8^{a}	$4.5^{a,b}$	$2.7^{a,b}$	$3.30^{a,b}$	1.6^{b}	0.37^{a}	0.31^{b}	0.38^{a}
$ZnSO_4$	73.6^{a}	12.5^{a}	3.1^{a}	10.1^{a}	4.0^{a}	23.5^{a}	14.6^{a}	0.75^{a}	0.85^{a}	0.52^{a}
truck tyre (surface)	0.44^{d}	$0.48^{d,e}$	0.17^{e}	0.25^{c}	0.14^{d}	n.d.	0.34^{c}	$0.04^{b,c}$	0.04^{c}	0.01^{c}
car tyre (surface)	n.d.	$0.69^{c,d}$	0.52^{c}	1.1^{b}	$1.0^{b,c}$	n.d.	0.12^{c}	0.10^{b}	0.04^{c}	0.03^{b}

n.d.: not detected

Table 3. Soil Zn mass balance after 11 months outdoor weathering in comparison with nominal application. Means followed by same character within columns are not significantly different at $\alpha<0.05$.

Treatment	soil B (acid sand)				soil T (silt loam)			
	total Zn soil[(1)] ±SD	Zn lost by leaching[(2)]	initial Zn[(3)]	nominal Zn application[(4)]	total Zn soil[(1)] ±SD	Zn lost by leaching[(2)]	initial Zn[(3)]	nominal Zn application[(4)]
	mg Zn/kg_{dw}				mg Zn/kg_{dw}			
Control	26 (1)	0.6[d]	27	0	37 (3)	0.2[b]	37	0
truck tyre	559 (69)	0.7[d]	560	714	511 (9)	1.6[b]	513	714
car tyre	318 (34)	2.1[c]	320	338	269 (16)	0.3[b]	269	338
ZnO	309 (10)	10.2[b]	319	360	305 (76)	2.6[a,b]	308	360
$ZnSO_4$	290 (6)	45.2[a]	335	360	294 (12)	16.5[a]	310	360
truck tyre (surface)	562 (94)	0.7[d]	563	714	532 (34)	0.3[b]	532	714
car tyre (surface)	251 (8)	0.6[d]	252	338	254 (24)	0.3[b]	254	338

(1) measured on oven dried soils sampled at 6-Oct-00; (2) calculated from Zn concentration in leachates and total leachate volume of soil columns sampled at 6-Oct-00 (data converted to soil dry weight); (3)=(1)+(2); (4) dry weight based

Table 4. The Potential Nitrification Rate (PNR, mg N kg^{-1} d^{-1}) in the soils sampled on two occasions. Means followed by same character within columns are not significantly different at $\alpha<0.05$. Reduced values of the PNR indicate stress on the nitrifying organisms.

Treatment	soil B (acid sand)				soil T (silt loam)			
	28-Feb-00		1-Sep-00		28-Feb-00		1-Sep-00	
	PNR	% of control	PNR	% of control	PNR	% of control	PNR	% of control
control	5.2[c]	100	3.5[c]	100	7.3[a]	100	5.1[a,b]	100
truck tyre	23.1[a]	440	16.6[a]	478	9.6[a]	131	6.5[a,b]	128
car tyre	9.2[b]	176	7.6[b]	218	6.6[a]	91	6.0[a,b]	119
ZnO	4.7[c]	89	3.7[c]	106	5.8[a]	79	5.6[a,b]	111
$ZnSO_4$	3.3[d]	63	3.2[c]	91	3.0[b]	41	4.6[b]	90
truck tyre (surface)	19.4[d]	371	15.3[a]	441	9.3[a]	128	7.0[a,b]	138
car tyre (surface)	8.3[b]	159	6.3[b]	181	8.7[a]	120	7.8[a]	153

Table 5. The radiolabile Zn content (E-value) in soils sampled on 6 October, 2000. Means and standard deviations (in brackets) of two replicates. The labile fraction of added Zn relative to total added Zn is calculated with Eqn (1).

treatment	**E value (mg Zn/kg)**	**Labile fraction of added Zn relative to total added Zn (%)**
	soil B (acid sand)	
control	13 (1)	
truck tyre	114 (8)	19 (3)
car tyre	128 (8)	39 (5)
ZnO	298 (16)	101 (7)
$ZnSO_4$	276 (5)	100 (3)
truck tyre (surface)	71 (14)	11 (3)
car tyre (surface)	78 (31)	29 (14)
	soil T (silt loam)	
control	11 (1)	
truck tyre	82 (5)	15 (1)
car tyre	80 (3)	30 (3)
ZnO	183 (46)	64 (25)
$ZnSO_4$	223 (24)	82 (10)
truck tyre (surface)	61 (3)	10 (1)
car tyre (surface)	55 (2)	20 (3)

Table 6. Pore water Zn concentrations relative to control values in soils sampled 1 year after application of tyre debris. Predictions are based on the radiolabile Zn concentration and soil pH (Eqn. 3) and observations are based on data of Table 2.

	soil B (acid sand)		**soil T (silt loam)**	
	predicted	***observed***	***predicted***	***observed***
control	1.0	1.0	1.0	1.0
truck tyre	0.8	0.6	2.4	2.0
car tyre	4.7	2.6	4.9	4.4
truck tyre (surface)	0.5	0.4	1.8	1.1
car tyre (surface)	3.1	3.1	2.7	3.6

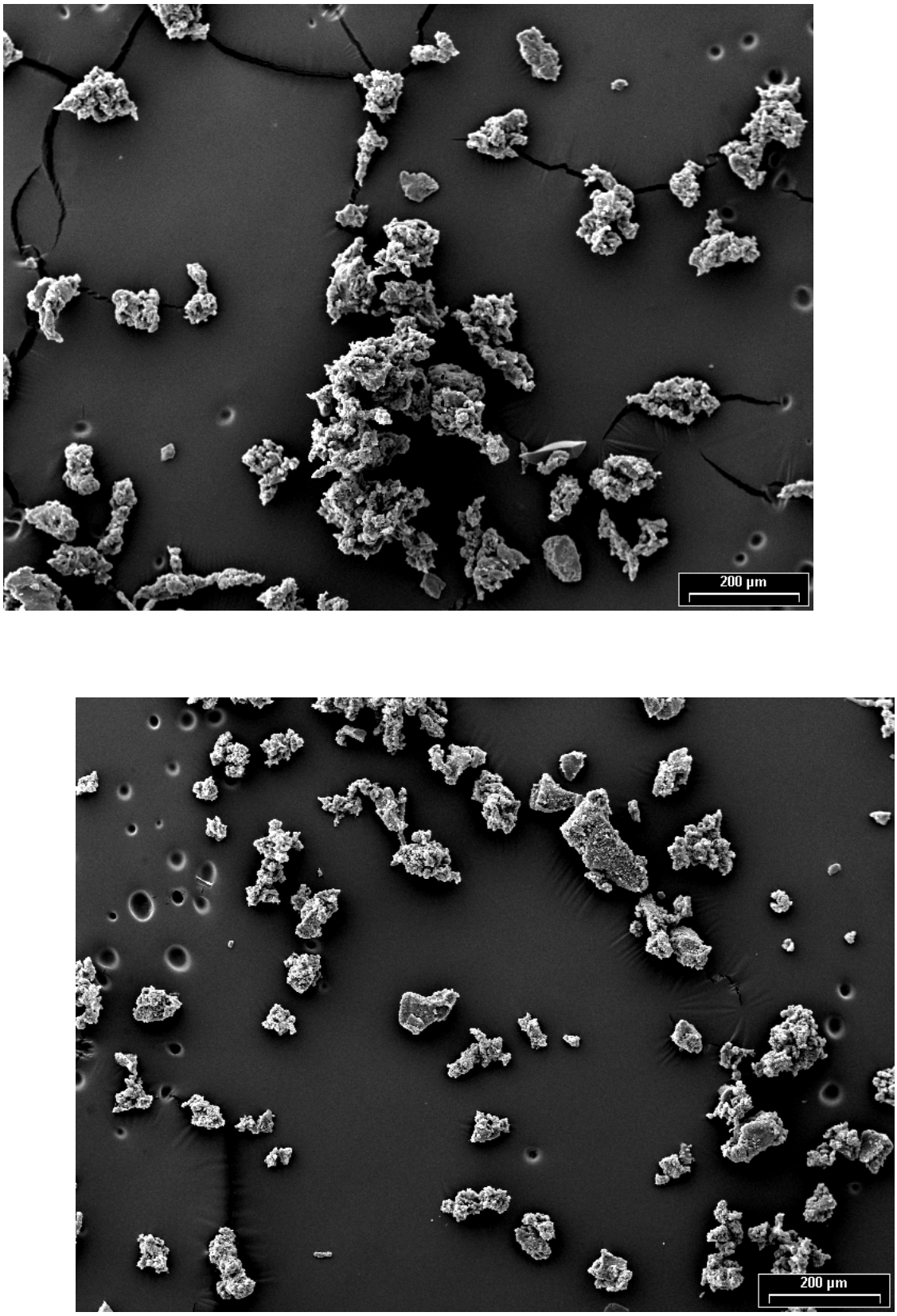

Figure 1. SEM photographs of the <100µm fraction of truck (top) and car (bottom) tyre debris

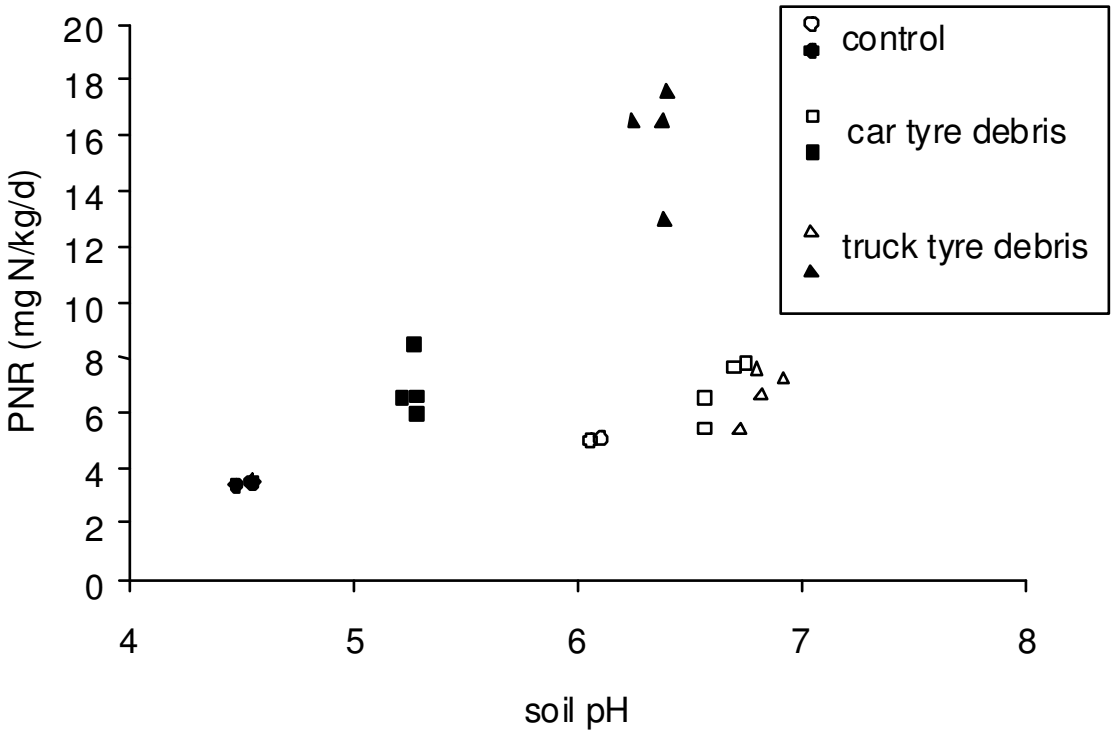

Figure 2. Soil pH and not soil Zn concentrations explain the Potential Nitrification Rate (PNR) in the soils amended with car/truck tyre debris (mixed or surface applied). Data of soils sampled 11 months after application of the debris. Open symbols: soil T(silt loam); closed symbols: soil B (acid sand)