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EFFECT OF POST-AGRICULTURAL SOILS AFFORESTATION ON ZINC AND LEAD SOLUBILITY

WPŁYW ZALESIENIA GLEB POROLNYCH NA ROZPUSZCZALNOŚĆ CYNKU I OŁOWIU

Abstract: Afforestation of post-arable soils changes their properties including reaction, organic matter and dissolved organic carbon content – the key factors in binding/mobilization of trace metals. However, the extensive literature reviews the impacts of afforestation of former arable soils on their properties, there is only limited knowledge on the trace metals behavior in response to such a shift of land use. This study presents the results concerning the effect of afforestation with Scots pine (*Pinus sylvestris* L.) of rusty (Distric Arenosols) post-arable soils formed on water-glacial sands on Zn and Pb solubility measured by their concentration in soil solution and a share in this phase in relation to the total content in soil. Soils under 14–17 years and 32–36 years old stands were compared with neighboring arable soils, five pairs each group. The soil samples were taken from the whole thickness of master horizons and, in the case of the A horizon of the afforested soils, from three layers: 0–5 (A_{0-5}), 5–10 (A_{5-10}) and 10–20 cm (A_{10-20}).

Zinc concentration in soil solution, both in mg · dm^{-3} and in percent in relation to the total soil content proved to be higher in the afforested soils than in the respective arable soils and was soil pH-dependent. The differences increased with the stand age. As for Pb, no such clear relationships were found.

Keywords: afforestation, post-agricultural soil, lead, zinc, solubility

Afforestation of post-agricultural soils has been one of the major land-use changes in many European countries in the recent decades [1–4]. It induces some changes in most of the soil properties: organic matter, pH, content of nitrogen and other elements, porosity, bulk density and biological activity [5–9]. Many of them, such as, pH and acidity, solid and dissolved organic carbon levels constitute the crucial factors affecting the retention/mobilization of trace metals present in a soil [10–13].

The vast available literature has put focus on the effect of afforestation of former agricultural land on soil properties but the impact of such land-use change on the behavior of trace elements still remains unclear. Therefore, as part of a study comparing

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post-arable sandy soils planted with Scots pine with arable soils, the effect of afforestation on the mobility of selected trace metals has been investigated.

The objective of this study was to determine the impact of afforestation of rusty (Distric Arenosols) post-arable soils on Zn and Pb solubility measured by their concentration in soil solution and a share in this phase in relation to the total content in the soil.

Material and methods

The present studies were conducted in the Lublin region. Ten paired sites of the afforested with Scots pine (*Pinus sylvestris* L.) former arable soils with adjacent cultivated fields were selected for the investigation. The locations were to represent two age classes of afforestation with five sites each, considered as replicates. At five stand sites, the stand age was 14–17 years (young stands) and at the other five ones – 32–36 years (older stands). All soils were developed on water-glacial sands and classified as the rusty type of soils (subtype proper) according to the Systematics of Polish Soils [14] and the Distric Arenosols in the WRB [15] classification [16]. The soils are light textured (loose sand and slightly loam sand). A system of crop rotation performed on all the analyzed fields was similar. In the sampling year, rye, oat and bird's-foot were grown at seven, two and one location, respectively. This region is characterized with low-intensity forms of agriculture and consequently, a very low fertilization rate. It was assumed that each pair of plots showed soil characteristics similar to those prior to afforestation and that arable soils served as control.

Soil samples were collected post harvest in the late summer. At each site, representative arable and forest profiles were excavated. Soil samples (ca 10 kg each) were taken from the whole thickness of each master horizon. Only the humus horizon of the afforested soils made the exception as the samples were collected from three layers, ie 0–5 ($A_{0–5}$), 5–10 ($A_{5–10}$) and 10–20 cm ($A_{10–20}$).

Soil pH was measured in 1 mole KCl · dm^{-3} at a 1:2.5 soil : solution ratio and measured electrometrically. A content of total Zn and Pb was determined in the extracts after digestion in a mixture of concentrated nitric(V) acid and 70 % chloric(VII) acids, followed by HCl leaching. A soil solution was established by centrifugation procedure following the soil incubation for 48 h at field capacity moisture and room temperature in darkness [17]. Both forms of metals were determined using the ICP-AES method (Leemman PS 950 apparatus).

A share of Zn and Pb concentrations in the soil solution as related to the total content in soil was calculated. Before that the concentrations of Zn and Pb in mg · dm^{-3} were recalculated as mg · kg^{-1} of soil dry mass using soil moisture at incubation.

Results and discussion

The mean total contents of Zn in solid phase, in soils of the 14–17 years old stand sites, both in the arable and in the afforested soils, were higher than in the respective soils of the 32–36 years old stand sites (Table 1).

Table 1

The content of Zn in soil, soil solution and its share in soil solution as related to the total content in soil; for Ap, A_{0-5}, A_{5-10}, A_{10-20}, Bv and C n = 5, for $A_{av.}$ n = 15

Soil use	Horizon/ layer	Total content in soil			Concentration in soil solution			Share			pH_{KCl} of soil
		Range	Mean	SD*	Range	Mean	SD	Range	Mean	SD	
		[mg · kg^{-1}]			[mg · dm^{-3}]			[%]			Range
14–17 years old stand sites											
Field	Ap	9.5–17.3	14.2	2.9	0.42–0.53	0.46	0.04	0.35–0.67	0.54	0.13	3.88–5.02
	Bv	9.3–14.1	12.2	1.9	0.18–0.38	0.30	0.09	0.18–0.38	0.29	0.09	4.34–4.69
	C	5.0–5.6	5.4	0.2	0.16–0.42	0.25	0.11	0.18–0.54	0.32	0.14	4.52–4.85
Forest	A_{0-5}	9.4–14.6	12.7	2.2	0.54–0.95	0.73	0.19	0.41–1.46	0.89	0.46	3.50–4.07
	A_{5-10}	8.9–14.1	12.2	2.0	0.43–0.91	0.61	0.24	0.40–1.09	0.77	0.32	3.70–4.08
	A_{10-20}	10.1–14.5	12.4	2.4	0.33–1.02	0.60	0.27	0.43–1.12	0.74	0.28	3.88–4.99
	A_{avg}	8.5–13.5	12.4	1.9	0.44–0.94	0.65	0.22	0.42–1.22	0.80	0.35	
	Bv	8.5–13.5	10.2	1.9	0.28–0.74	0.42	0.19	0.34–0.83	0.53	0.25	4.24–4.67
	C	3.6–8.0	5.6	1.7	0.25–0.66	0.42	0.19	0.31–0.88	0.61	0.25	4.44–4.60
32–36 years old stand sites											
Field	Ap	10.1–17.5	12.1	3.1	0.47–1.01	0.65	0.22	0.34–1.50	0.81	0.43	4.08–4.38
	Bv	4.2–14.2	8.9	3.8	0.31–0.53	0.37	0.09	0.33–0.76	0.52	0.16	4.50–4.64
	C	1.5–6.1	3.7	1.8	0.22–0.35	0.28	0.06	0.37–0.79	0.60	0.20	4.65–4.72
Forest	A_{0-5}	7.4–9.7	8.5	1.0	0.67–1.56	1.15	0.37	1.17–2.39	1.77	0.56	3.16–3.50
	A_{5-10}	6.1–10.6	8.2	1.6	0.66–1.64	0.94	0.40	0.98–2.01	1.31	0.41	3.56–3.80
	A_{10-20}	6.8–10.9	8.8	1.5	0.42–0.75	0.57	0.14	0.51–1.00	0.77	0.19	3.73–4.03
	A_{avg}	6.8–10.4	8.5	1.3	0.58–1.32	0.89	0.28	0.89–1.76	1.29	0.35	
	Bv	6.0–7.9	7.4	0.8	0.30–0.72	0.52	0.16	0.43–1.20	0.86	0.37	4.31–4.47
	C	2.5–5.3	3.8	1.1	0.27–0.57	0.37	0.11	0.46–1.11	0.77	0.27	4.49–4.63

* Standard deviation.

In the afforested soils, the total content of Zn, average in the whole humus horizon, reached 12.4 and 8.5 mg · kg^{-1} for soils of young and older stands, respectively. It was slightly lower than in Ap horizon of the related arable soils amounting 14.2 and 12.1 mg · kg^{-1}, respectively. The content of Zn decreased with the depth and in the Bv horizon of the afforested soils (in both sites) it appeared to be lower compared with the respective horizon of the arable soils, whereas similar in the C horizon.

The Zn mean concentration in the soil solution ranged from 0.25 up to 1.15 mg · dm^{-3}, subject to a horizon and soil use. In contrast to the total soil content, in all the horizons and layers (with one exception), it was higher in the solutions of the afforested soils as against the respective solutions of the cultivated soils.

Similarly, a share of Zn in the soil solution in relation to its total soil content was higher in the afforested soils (mean of $A_{av.}$ was 0.80 and 1.29 % for young and older stand sites, respectively) than in the Ap horizon of the related arable soils (0.54 and 0.81 %). Moreover, it was substantially higher in soils of the older than young stands.

Results indicate that afforestation of the studied post-arable soils caused Zn release from the solid phase to the soil solution. It emerged as a consequence of changes in soil reaction, a main factor influencing the solubility of zinc compounds [18, 19], after pine trees planting. The present study has revealed a significant, negative correlation between Zn concentration in soil solution and soil pH (Fig. 1).

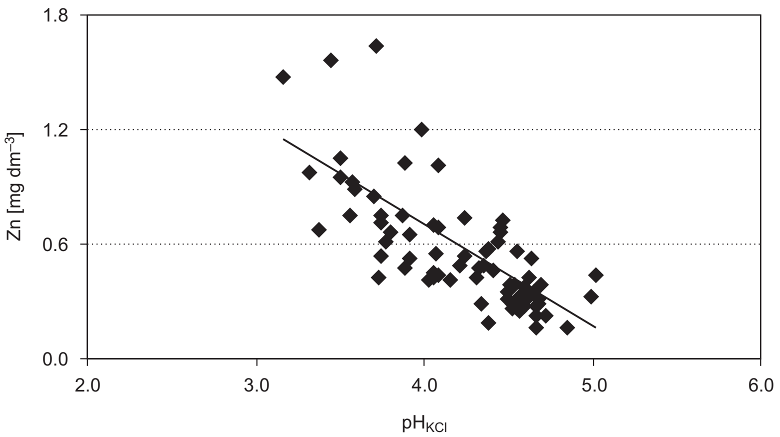

Fig. 1. Relationship between the Zn concentration in soil solution and pH of soils

Besides, as Table 1 presents, the afforested soils, under both young and older stands, showed stronger acidity (as measured by pH_{KCl}) in all the layers, especially in the A_{0-5} of the humus horizons than in the corresponding Ap horizons of the arable soils. Moreover, the pH values in these horizons appeared to be lower in the soils of older than young stands, which explains the higher contents and share of Zn in the soil solution in the first and not the other case.

The higher Zn concentrations in the soil solution of the afforested soils compared with the arable soils have confirmed our preliminary results [20] and agreed with data

Table 2

The content of Pb in soil, soil solution and its share in soil solution as related to the total content in soil; for Ap, A_{0-5}, A_{5-10}, A_{10-20}, Bv and C n = 5, for $A_{av.}$ n = 15

Soil use	Horizon/ layer	Total content in soil			Concentration in soil solution			Share		
		Range	Mean	SD*	Range	Mean	SD	Range	Mean	SD
		[mg · kg^{-1}]			[mg · dm^{-3}]			[%]		
14–17 years old stand sites										
Field	Ap	7.5–12.2	9.4	1.9	0.101–0.298	0.209	0.077	0.17–0.63	0.37	0.18
	Bv	3.9–5.7	4.6	0.8	0.067–0.190	0.147	0.047	0.22–0.44	0.37	0.09
	C	2.6–5.0	3.5	0.9	0.015–0.192	0.112	0.064	0.02–0.49	0.26	0.18
Forest	A_{0-5}	6.8–9.7	8.0	1.3	0.227–0.495	0.374	0.104	0.40–1.18	0.68	0.33
	A_{5-10}	7.3–10.9	8.8	1.7	0.169–0.471	0.307	0.110	0.30–0.71	0.53	0.20
	A_{10-20}	6.2–9.3	7.8	1.3	0.061–0.423	0.237	0.139	0.14–0.82	0.49	0.31
	A_{avg}	7.0–9.8	8.2	1.2	0.152–0.429	0.306	0.106	0.28–0.88	0.57	0.22
	Bv	2.6–4.4	3.7	0.8	0.001–0.374	0.136	0.149	0.002–1.21	0.46	0.56
	C	2.5–4.2	3.4	0.8	0.001–0.087	0.043	0.037	0.001–0.19	0,09	0.07
32–36 years old stand sites										
Field	Ap	7.1–13.1	9.0	2.5	0.034–0.296	0.130	0.103	0.05–0.77	0.25	0.30
	Bv	2.6–5.2	3.9	0.9	0.025–0.139	0.061	0.047	0.07–0.37	0.17	0.12
	C	2.2–3.7	3.0	0.6	0.001–0.194	0.064	0.087	0.001–0.44	0.15	0.20
Forest	A_{0-5}	8.6–10.8	9.7	0.9	0.173–0.267	0.198	0.040	0.17–0.53	0.29	0.14
	A_{5-10}	7.3–8.4	7.8	0.4	0.008–0.307	0.153	0.116	0.009–0.65	0.27	0.25
	A_{10-20}	5.3–9.5	8.4	1.8	0.018–0.259	0.100	0.098	0.03–0.29	0.14	0.11
	A_{avg}	7.6–9.2	8.6	0.6	0.073–0.230	0.150	0.058	0.07–0.47	0,23	0.15
	Bv	1.7–4.9	3.7	1.3	0.001–0.233	0.099	0.099	0.002–0.76	0.34	0.34
	C	2.5–5.0	3.8	0.9	0.001–0.176	0.078	0.075	0.0009–0.32	0.16	0.15

* Standard deviation.

reported by Römkens and Salomons [12], Smal [17] as well as Smal et al [21] in the study comparing cultivated soils with natural forest soils.

The content of total Pb in solid phase has not shown clear differences between investigated sites. In the arable soils, similarly to Zn, it was slightly higher, whereas in the afforested soils it tended to be lower (in A and C horizons) in soils of the 14–17 years old than in the 32–36 years old stand sites.

In the afforested soils, the content of total Pb, average in the whole humus horizon, was equal to 8.2 and 8.6 mg · kg^{-1}, for soils of the young and older stands, respectively and slightly lower than in the respective horizon of the arable soils (9.4 and 9.0 mg · kg^{-1}) (Table 2). In the deeper horizons, it proved to be lower than in the A horizons and similar in all soils.

Total Pb values established were comparable with the data for forest Haplic Arenosols reported by Kalembasa et al [22].

For both total Pb and its soluble forms content, no marked relationships between the compared groups of soils were found. In the soils under young forests, similarly to zinc, a mean content of total Pb in the soils of humus horizons was lower (mean $A_{av.}$ of 8.2 mg · kg^{-1}), whereas in the soil solution for all layers and average for a former plough layer it was notably higher (mean $A_{av.}$ of 0.306 mg · dm^{-3}) than in the related horizons of the arable soils (mean Ap of 9.4 mg · kg^{-1} and 0.209 mg · dm^{-3}, respectively). In turn, in a soil group comprising older stand sites, for both Pb forms, only very slight differences in their content in humus horizons between afforested and cultivated soils were observed.

Similarly, a share of Pb in the soil solution in relation to its total soil content did not show any evident pattern. It was much elevated in the humus horizons in the afforested soils under the young stands, while in the soils under the older stands – even slightly lower as compared with the respective horizons of the arable soils. What is more, in contrast to Zn, a Pb share in the soil solution related to its total soil content turned out to be higher in the soils under the young (0.57 %) than older stand sites (0.23 %).

The obtained results indicate the stronger effect of pine trees on Zn mobility rather than Pb compounds in former arable soils. This would be consistent with the findings reported by Andersen et al [1] who studying distribution and fractionation of heavy metals in pairs of arable and afforested with Norway spruce soils in Denmark observed some tendency of Zn movement with no increase in Pb solubility or movement.

Conclusions

1. The present study indicates that forest vegetation caused an increase in Zn solubility in the former arable soils. This metal concentrations in the soil solution, both in mg · dm^{-3} and in percent of the total soil content, were higher in the afforested soils compared with the respective arable soils, being soil pH-dependent. The differences tended to increase with the stand age.

2. In the case of Pb, no clear effect of pine trees on the studied metals solubility was observed.

3. The findings imply that afforestation of sandy arable soils causes soil acidity increase and thereby, is likely to enhance mobility of Zn compounds in soil environment and their downward movement.

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WPŁYW ZALESIENIA GLEB POROLNYCH NA ROZPUSZCZALNOŚĆ CYNKU I OŁOWIU

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Abstrakt: Zalesienie gleb porolnych wywołuje zmiany ich właściwości, w tym odczynu, zawartości materii organicznej, rozpuszczonego węgla organicznego, które regulują zatrzymywanie/uruchamianie pierwiastków śladowych w glebie. Mimo obszernej literatury dotyczącej wpływu zalesienia dawnych gleb uprawnych na właściwości gleb, mało wiadomo o skutkach takiej zmiany użytkowania na zachowanie się pierwiastków śladowych. W pracy przedstawiono wyniki badań wpływu zalesienia sosną zwyczajną gleb rdzawych porolnych wytworzonych z piasków wodnolodowcowych na rozpuszczalność Zn i Pb mierzoną zawartością tych metali w roztworze glebowym i ich udziałem w tej fazie w stosunku do całkowitej zawartości w glebie. Porównywano gleby pod drzewostanami 14–17- i 32–36-letnimi z sąsiadującymi z nimi glebami uprawnymi, po pięć par w każdej grupie. Próbki glebowe pobierano z każdego głównego poziomu genetycznego, z całej jego miąższości, przy czym z poziomu A gleb zalesionych z trzech warstw: 0–5 (A_{0-5}), 5–10 (A_{5-10}) i 10–20 cm (A_{10-20}).

Stwierdzono, że stężenie Zn zarówno w mg · dm^{-3}, jak i w procentach w odniesieniu do całkowitej zawartości w glebie, było większe w glebach zalesionych niż w glebach ornych i było zależne od pH gleby. Ponadto różnice zwiększały się wraz z wiekiem drzewostanu. W przypadku Pb nie zaobserwowano takich wyraźnych prawidłowości.

Słowa kluczowe: zalesienia, gleby porolne, cynk, ołów, rozpuszczalność