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CONTENT RATING OF CHOSEN TRACE ELEMENTS IN PLANTS AND SOIL AFTER APPLICATION OF NEWSPAPER WASTE

OCENA ZAWARTOŚCI WYBRANYCH PIERWIASTKÓW ŚLADOWYCH W ROŚLINACH I GLEBIE PO APLIKACJI PAPIERU GAZETOWEGO

Abstract: The research was conducted to determine the content of Cr, Cd, Ni and Pb in soil and plant biomass after application of newspaper waste. The pot experiment was conducted in the years 2010 and 2011 in the greenhouse and included the following objects: NP-0 soil without addition of newspaper, NP-1 the soil with addition of 1 % of newspaper and NP-3 the soil with addition of 3 % of newspaper. Addition of newspaper was calculated relative to the dry weight of the soil material. The study was conducted in pots containing 5.50 kg of air-dried soil material. Two plants were grown in the experiment: spring rape, 'Felix' c.v., in the first year and naked oats, 'Siwek' c.v., in the second. Rape was collected at the end of the flowering stage (73-day vegetation period), and oats at grain milk stage (75 days of vegetation). After preparation of plant material and soil, content of trace elements was determined by ICP-OES method on a Perkin Elmer Optima 7300DV apparatus. The results were converted to absolute dry weight of the material.

Application of newspaper to soil did not increase (except for cadmium) the contents of lead, chromium or nickel in the aboveground parts of the plant. Studied trace elements were accumulated mainly in the plant roots. Roots contained on average from 51 to 82 % more of the test elements in relation to the aboveground parts. Higher amount of newspaper (3 %) added to the soil led to a higher accumulation of studied trace elements in the roots and lower in the plant aboveground parts. The addition of newspaper to the soil caused a reduction in acidity. Newspaper introduced to the soil generally did not increase the total content of trace elements.

Keywords: newspaper, soil, plants, trace elements

Introduction

Paper belongs to the biodegradable wastes which in compliance with act on wastes should not be deposited in landfills [1]. It has been estimated that in the EU countries

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about 60 % of the total annual production of paper finds its way to landfills, of which on average 4 % is a newsprint [2]. Seeking the opportunities for repeated use of material of low suitability for recycling makes necessary finding new solutions allowing to reduce the biodegradable biomass which is deposited in landfills. Newsprint manufactured from recycled paper may provide a potential raw material enriching soil in organic matter. An additional asset of the paper is wide C:N ratio (398-852:1) [1]. Another opportunity of newspaper management may be its composting with other biodegradable wastes [4]. A supplement of such component to the composted biomass may improve the conditions for the process (mainly due to decrease in water content) and in result improve the structure of produced wastes. However, it should be remembered that an addition of newspaper fraction to the soil or composted fraction of biodegradable waste may also generate negative results. An example of unfavourable effect of newspaper on the soil environment or generated biomass may be an increase in trace element contents, which constitute an integral part of newspaper inks [5].

The investigations aimed at an assessment of Cr, Cd, Ni and Pb contents in the soil and plant biomass after the application of newspaper.

Material and methods

The research on the effect of newspaper application on the content of selected trace elements in the soil and plant biomass was conducted in 2010–2011 as a pot experiment in the vegetation hall of the Faculty of Agriculture and Economics, University of Agriculture in Krakow.

The experimental design comprised three objects in 4 repetitions: NP-0 – control (soil without newspaper supplement), NP-1 – soil with 1 % admixture of newspaper and NP-3 – soil with 3 % addition of newspaper. Newspaper supplement was calculated in relation to the soil material dry weight. Newspaper mass before the application to the soil was crushed mechanically in paper shredder. Characteristics of selected properties of the newspaper used for the experiment were shown in Table 1.

Table 1

Selected properties of newspaper and soil before experiment (0–20 cm)

| Determination | Unit | Newspaper | Soil |
|---------------------------|------------------------------|-------------|-------------|
| pH in H ₂ O | — | 6.25 ± 0.03 | n.d. |
| pH in KCl | — | n.d. | 5.81 ± 0.22 |
| Electrolytic conductivity | [mS · cm ⁻¹] | 7.41 ± 0.04 | 0.12 ± 0.01 |
| Organic C | [g · kg ⁻¹ d.m.] | 294 ± 4 | 9.08 ± 0.48 |
| Total N | | 16.4 ± 0.1 | 1.16 ± 0.03 |
| Total Ni | | 22.0 ± 0.2 | 9.88 ± 0.25 |
| Total Cr | | 45.0 ± 3.3 | 13.2 ± 0.5 |
| Total Cd | [mg · kg ⁻¹ d.m.] | 0.10 ± 0.07 | 1.00 ± 0.07 |
| Total Pb | | 1.36 ± 0.27 | 25.4 ± 1.1 |

± standard deviation, n = 2; n.d. – not determined.

The experiment was conducted in plastic pots containing 5.50 kg of air-dried soil material. The soil material was ordinary loam collected from 0–20 cm arable layer of ploughland located at the experimental station of the University of Agriculture in Mydlniki. Selected properties of the soil material prior to the investigations were assessed using methods commonly applied in agricultural chemistry [6]. Properties of the soil materials were presented in Table 1.

In the first year of research the test crop was spring rape, 'Feliks' c.v., and in the second naked oats, 'Siwek' c.v. Rape was harvested by the end of flowering stage (73 days of vegetation), while rape at grain milk maturity (75 days of vegetation). The plants were harvested and divided into aboveground parts and roots. The plant material was dried at 70 °C in a drier with air flow and the dry weight yield was determined. Then it was ground in a laboratory mill and subjected to chemical analyses. Biomass obtained from the test plants was subjected to independent chemical analyses when the subsequent vegetation seasons of rape and oats ended. Mean weighted contents of analysed trace elements were computed from the results obtained for both plants.

Dried and ground plant material was mineralized in a chamber furnace (at 450 °C for 5 h). The remains were dissolved in diluted nitric acid (1:2, v/v) [6]. The content of nickel, chromium, cadmium and lead in the obtained solutions was assessed by means of ICP-OES method on Perkin Elmer Optima 7300DV apparatus and the obtained results were converted into the plant material absolute dry mass.

The soil material was collected after each year of the experiment, dried at room temperature, crushed in a porcelain mortar and sifted through a sieve with 1 mm mesh. In the material prepared in this way pH was determined by potentiometer in the suspension of soil material and 1 mol · dm⁻³ KCl solution, electrolytic conductivity by conductometer and the content of total trace elements after organic substance incineration in a chamber furnace (at 500 °C for 8 hours) and mineralization of the residue in a mixture of concentrated nitric and perchloric acids (2:1, v/v). The concentrations of analysed elements were assessed in the obtained solutions using ICP-OES method on Perkin Elmer Optima 7300DV apparatus.

A one-way ANOVA in the completely randomized design using f-Fisher test was conducted for the obtained results. The significance of differences between arithmetic means was verified on the basis of homogenous groups created by Tukey's test at the significance level $\alpha \leq 0.05$. All statistical computations were made using Statistica PL packet [7].

Results and discussion

Biodegradation of newspaper waste in soil is a complicated process, primarily basing on lignin degradation. The content of this component may reach even 20 % of dry matter [8]. Research of Tuomela et al [4] show that the theoretical degree of paper biodegradation at 15 % content of lignin is 41 %. Considering the fact that humus is formed mainly of lignin, the share of the other paper components, such as cellulose or hemicellulose is less important [9].

Paper is a material which, due to a considerable proportion of complex organic compounds (lignin), does not undergo a total mineralization. It decomposition is

conducted primarily by thermophilous fungi and actinomycetes [4]. It is believed that the microorganisms capable of cellulose hydrolysis, responsible for paper biodegradation appear already at the stage of production. Their destructive effect on newspaper is much more serious than in case of other paper wastes. It is caused not only by the paper weight itself, but also the kind of raw material of which it was manufactured. In case of newspaper, which is a recycled product (recycled paper), low quality of the raw product which weakens the final product, is visible [10]. Development of cellulolytic fungi causes not only changes on the paper surface but also leads to chemical and physical changes in its structure [11]. The outcome of the changes may be accelerated migration of trace elements present in printers ink to the soil solution.

Trace elements penetrating into the soil with applied material may undergo various changes. These changes may have a significant influence on the quantity of compounds directly available to plants [12, 13].

Presented research has shown that the highest total amount of plant biomass was obtained in the object where no newspaper was supplied (NP-0). Significantly the smallest biomass amount was harvested from the object where 3 % of newspaper supplement was added (NP-3) in relation to the soil material dry weight (Fig. 1).

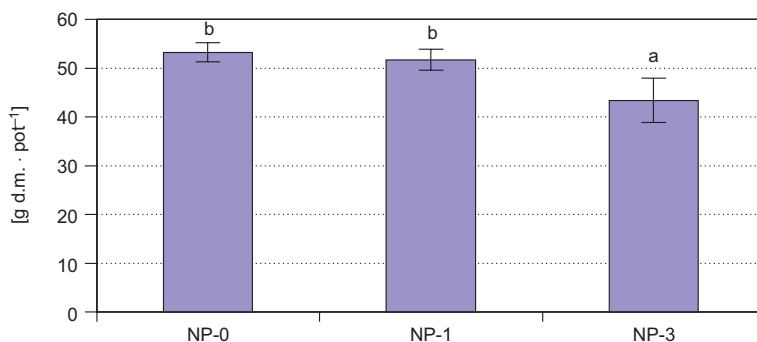


Fig. 1. The total amount of biomass oats and spring rape. Means followed by the same letters did not differ significantly at $\alpha \leq 0.05$ according to the t-Tuckey test

Independently of the amount of newspaper added to the soil, a decrease in weighted average amount of chromium, nickel and lead was noted in spring rape and oats aboveground parts in comparison with the content assessed in the aboveground parts of plants from the control (NP-0). It was observed that biomass of the aboveground parts of plants from the object which received 1 % newspaper supplement contained on average from 33 % to 53 % less of the analysed trace elements. On the other hand, a 3 % admixture of newspaper to the soil contributed to a decline in weighted average content of chromium, nickel and lead even by 63 % (Table 2).

Research conducted by Domanska [14] evidenced that plant aboveground parts contain much smaller amounts of nickel than roots. On the other hand, Antonkiewicz and Jasiewicz [15] observed that nickel is a relatively mobile element, easily absorbed by plants, whereas its translocation to the aboveground plant parts is greatly impeded. On the other hand, Gambus [16] thinks that the relationship of this type is conditioned

by the properties of the plant itself. In case of nickel uptake by plants, also this element interactions with other trace elements, such as cadmium or zinc are crucial.

Table 2

Weighted mean cadmium, chromium, nickel and lead in the above-ground parts of spring rape and oats

| Object | Cd | Cr | Ni | Pb |
|--------|------------------------------|--------------------------|--------------------------|--------------------------|
| | [mg · kg ⁻¹ d.m.] | | | |
| NP-0 | 0.70 ^b ± 0.22 | 4.77 ^b ± 1.21 | 4.50 ^b ± 1.53 | 1.27 ^a ± 0.37 |
| NP-1 | 1.68 ^a ± 0.13 | 2.73 ^a ± 0.14 | 2.12 ^a ± 0.03 | 0.85 ^a ± 0.07 |
| NP-3 | 1.55 ^a ± 0.21 | 2.78 ^a ± 0.37 | 1.68 ^a ± 1.68 | 0.84 ^a ± 0.18 |

± standard deviation, n = 8; Means followed by the same letters in columns did not differ significantly at $\alpha \leq 0.05$ according to the t-Tuckey test.

An opposite relationship was registered for cadmium. Mean weighted content of this element in plants from the objects with newspaper waste supplement increased twice in comparison with the content noted in biomass from the control (NP-0). The differences were statistically significant.

Mean weighted average of chromium, nickel and lead assessed in the roots of rape and oats from the objects where newspaper supplement was added to the soil was smaller in comparison with these element concentrations determined in plant roots from the control (NP-0). Mean weighted average content of chromium in roots diminished by 56 % on NP-1 object and by 26 % on NP-3 object. For nickel the decrease was respectively 36 % (NP-1) and 6 % (NP-3) and for lead 42 % (NP-1) and 6 % (NP-3) in comparison with the control (NP-0). For cadmium content in plant roots (like in aboveground parts) an increase in its content was registered in the biomass from the objects which received a newspaper supplement. The increase for NP-1 object was 22 % and for NP-3 – 18 %. Irrespective of the analysed element, the assessed content generally did not differ statistically (Table 3).

Table 3

Weighted mean cadmium, chromium, nickel and lead in the roots of spring rape and oats

| Object | Cd | Cr | Ni | Pb |
|--------|------------------------------|----------------------------|--------------------------|--------------------------|
| | [mg · kg ⁻¹ d.m.] | | | |
| NP-0 | 2.34 ^a ± 0.99 | 17.35 ^b ± 1.81 | 9.57 ^a ± 1.22 | 6.97 ^a ± 5.22 |
| NP-1 | 2.85 ^a ± 0.06 | 11.12 ^a ± 0.85 | 7.06 ^a ± 0.34 | 5.14 ^a ± 1.06 |
| NP-3 | 2.77 ^a ± 0.34 | 13.82 ^{ab} ± 2.91 | 9.06 ^a ± 1.62 | 4.02 ^a ± 0.52 |

± standard deviation, n = 8; Means followed by the same letters in columns did not differ significantly at $\alpha \leq 0.05$ according to the t-Tuckey test.

According to Kabata-Pendias and Pendias [17], lead and chromium are elements little mobile in the soil environment. Research conducted by Lentynska-Synos [17] reveals that chromium uptake and transport in plants are connected mainly with iron

presence. The amounts of cadmium absorbed by plants are directly proportional to this element content in the soil solution (irrespective of pH). Lentynska-Synos also thinks that cadmium is deposited mainly in roots and its natural content in plants is diversified depending on the species, as has been corroborated by the Author's own studies.

Chromium and nickel quantities absorbed by plant biomass in the objects with an admixture of newspaper to the soil were markedly smaller in comparison with these elements amount taken up by plants in the object where no newspaper was added. The experiment did not reveal any significant differences in the amounts of lead taken up by the plant biomass from individual objects. Total uptake of cadmium by spring rape and oats biomass from the objects with newspaper waste supplement was significantly higher than Cd quantities absorbed by plants in the control (Table 4).

Table 4

Total uptake of cadmium, chromium, nickel and lead with plants biomass

| Object | Cd | Cr | Ni | Pb |
|--------|---------------------------|--------------------------|--------------------------|--------------------------|
| | [mg · pot ⁻¹] | | | |
| NP-0 | 0.05 ^a ± 0.02 | 0.34 ^b ± 0.06 | 0.27 ^b ± 0.27 | 0.11 ^a ± 0.06 |
| NP-1 | 0.09 ^{ab} ± 0.01 | 0.19 ^a ± 0.01 | 0.14 ^a ± 0.14 | 0.07 ^a ± 0.01 |
| NP-3 | 0.07 ^b ± 0.00 | 0.17 ^a ± 0.17 | 0.11 ^a ± 0.02 | 0.05 ^a ± 0.01 |

± standard deviation, n = 8; Means followed by the same letters in columns did not differ significantly at $\alpha \leq 0.05$ according to the t-Tuckey test.

Presented experiment has revealed that application of newspaper to the soil led to a decrease in its acidification (Table 5). In the object with 3 % newspaper supplement pH value increased by 10 % in comparison with pH value assessed in the soil material before the experiment outset.

Determined values of electrolytic conductivity for the soil with 1 % and 3 % additions of newspaper were 0.25 mS · cm⁻¹ and 0.38 m · cm⁻¹, respectively (Table 5). These values were higher than noted in the initial soil (Table 1) and in the soil from the control (NP-0) (Table 5).

Table 5

The values of pH and electrolytic conductivity in the soil
(mean of two years)

| Object | pH KCl | Electrolytic conductivity [mS · cm ⁻¹] |
|--------|--------------------------|---|
| NP-0 | 5.15 ^a ± 0.03 | 0.05 ^a ± 0.01 |
| NP-1 | 5.79 ^b ± 0.02 | 0.25 ^c ± 0.03 |
| NP-3 | 6.38 ^c ± 0.18 | 0.38 ^d ± 0.03 |

± standard deviation, n = 8; Means followed by the same letters in columns did not differ significantly at $\alpha \leq 0.05$ according to the t-Tuckey test.

The effect of high value of electrolytic conductivity (regarded as the measure of soil salinity) is evidenced mainly as an impediment in water uptake [19]. The critical value of electrolytic conductivity impeding plant growth is regarded as the limit value of $1.0 \text{ mS} \cdot \text{cm}^{-1}$ [20]. Application of a bigger amount of newspaper waste to the soil contributed to its greater salinity, which in turn might have directly influenced a weaker plant development.

Investigations show that average for two years total contents of nickel, cadmium and lead in the soil in the objects where 1 % and 3 % newspaper supplement was added to the soil were lower in comparison to their concentrations assessed in the soil material from the control (NP-0). Cadmium content determined in NP-1 and NP-3 objects was twice lower in comparison with the amounts in the soil material from the object where no newspaper was added (NP-0) (Table 6).

Table 6

Mean content (of two years) of Cd, Cr, Ni and Pb in soil

| Object | Cd | Cr | Ni | Pb |
|--------|------------------------------|----------------------------|--------------------------|---------------------------|
| | [mg · kg ⁻¹ d.m.] | | | |
| NP-0 | 0.83 ^b ± 0.11 | 13.14 ^{ab} ± 0.23 | 9.35 ^a ± 0.31 | 24.97 ^b ± 0.81 |
| NP-1 | 0.47 ^a ± 0.02 | 13.96 ^b ± 0.70 | 9.13 ^a ± 0.08 | 23.24 ^a ± 0.34 |
| NP-3 | 0.44 ^a ± 0.01 | 12.68 ^a ± 1.34 | 9.00 ^a ± 0.19 | 22.74 ^a ± 0.47 |

± standard deviation, n = 8; Means followed by the same letters in columns did not differ significantly at $\alpha \leq 0.05$ according to the t-Tuckey test.

Statistical analysis of the results confirmed the significance of differences. A much weaker effect of dilution was observed for nickel and lead. Nickel concentration after the application of 1 % and 3 % newspaper supplement in relation to soil material dry weight contributed to a decrease in nickel content in the soil material by 2.4 % in NP-1 object and 3.8 % in NP-3 object. The situation was similar for lead, where the decreases in this element content were 7.4 % and 9.1 %, respectively, in comparison with the control (NP-0). The exception was chromium of which 6.2 % higher concentration was assessed in NP-1 object.

Total content of trace elements in biodegradable waste materials, such as newspaper allows to determine their potential environmental applications [21]. The literature data confirm the relationship between total content of trace elements in soil and their concentrations in plants. On the other hand, the quantities of trace elements accumulated by plants depend on the rate of trace element translocation from the waste materials to the soil solution and also on the biomass amount.

Conclusions

1. Newspaper application to the soils did not lead to an increase (except for cadmium) in the contents of lead, chromium or nickel in plant aboveground parts.

2. Analysed trace elements were accumulated mainly in plant roots. In relation to the aboveground parts, the roots contained on average from 51 % to 82 % greater quantities of the studied elements.

3. A bigger supplement of newspaper (3 %) to the soil affected a greater accumulation of the analysed trace elements in the roots and lower in the plant aboveground parts.

4. Newspaper supplement to the soil caused lowering its acidification.

5. Application of newspaper to the soil generally did not affect the total content of analysed trace elements.

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OCENA ZAWARTOŚCI WYBRANYCH PIERWIĄTKÓW ŚLADOWYCH W ROŚLINACH I W GLEBIE PO APLIKACJI PAPIERU GAZETOWEGO

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Abstrakt: Przeprowadzone badania miały na celu ocenę zawartości Cr, Cd, Ni i Pb w glebie oraz w biomasie roślin po aplikacji papieru gazetowego. Doświadczenie wazonowe prowadzono w latach 2010 i 2011 w hali vegetacyjnej. Doświadczenie obejmowało następujące obiekty: NP-0 – kontrola (gleba bez dodatku papieru gazetowego), NP-1 – gleba z 1 % dodatkiem papieru gazetowego oraz NP-3 – gleba z 3 % dodatkiem papieru gazetowego. Dodatek papieru gazetowego obliczono w stosunku do suchej masy materiału glebowego. Badania prowadzono w wazonach mieszczących 5,50 kg powietrznie suchego materiału glebowego. W doświadczeniu uprawiano dwie rośliny, w pierwszym roku rzepak jary odmiany ‘Feliks’, natomiast w drugim owies nagoziarnisty odmiany ‘Siwek’. Rzepak jary zbierano w końcu fazy kwitnienia (73 dni wegetacji), a owies w fazie dojrzałości młecznicy (75 dni wegetacji). Po odpowiednim przygotowaniu materiału roślinnego i glebowego, zawartość badanych pierwiastków śladowych oznaczono metodą ICP-OES na aparacie Perkin Elmer Optima 7300DV, a uzyskane wyniki przeliczono na absolutnie suchą masę materiału. Dogłębowa aplikacja papieru gazetowego nie spowodowała zwiększenia zawartości (za wyjątkiem kadmu) ołowiu, chromu i niklu w częściach nadziemnych roślin. Badane pierwiastki śladowe były gromadzone głównie w korzeniach roślin. W stosunku do części nadziemnych roślin korzenie zawierały średnio od 51 % do 82 % więcej badanych pierwiastków. Większy dodatek papieru gazetowego (3 %) do gleby skutkowało większą akumulacją badanych pierwiastków śladowych w korzeniach, a mniejszą w częściach nadziemnych roślin. Dodatek papieru gazetowego do gleby spowodował zmniejszenie zakwaszenia. Wprowadzenie do gleby papieru gazetowego na ogół nie wpłynęło na zwiększenie ogólnej zawartości badanych pierwiastków śladowych.

Słowa kluczowe: papier gazetowy, gleba, rośliny, pierwiastki śladowe

