

IMPACT OF SOIL CONTAMINATION WITH FLUORINE
ON THE CONTENT OF POTASSIUM IN THE BIOMASS OF CROPS

Radosław Szostek¹, Zdzisław Ciećko^{1,2}

¹Department of Environmental Chemistry, University of Warmia and Mazury
Plac Łódzki 4, 10-727 Olsztyn, Poland
e-mail: radoslaw.szostek@uwm.edu.pl

²Faculty of Ecology, University of Ecology and Management in Warsaw
ul. Olszewska 12, 00-792 Warszawa, Poland

Abstract. The paper presents results of a study on the influence of fluorine-contaminated soil, supplemented with lime, charcoal and loam, on the content of potassium in eight species of crops. The experiments consisted of eight greenhouse pot trials in 2009-2011. The following factors were tested: I – increasing doses of fluorine in the form of potassium fluoride; II – substances neutralising the soil contamination with fluorine. The content of potassium in plants varied, depending on the degree of soil contamination with fluorine, the application of substances inactivating this xenobiotic element, and on the plant species and organs. The highest mean potassium concentration was detected in the aerial biomass of phacelia (46.4 g K kg⁻¹ d.m.) and winter oilseed rape (45.9 g K kg⁻¹ d.m.), while the lowest one was assayed in the grain and straw of spring triticale (5.3 and 7.9 g K kg⁻¹ d.m.). The increasing degree of soil contamination with fluorine contributed to an increase in the average content of potassium in maize, narrow-leaf lupine, winter oilseed rape, black radish, the aerial biomass of yellow lupine and the aerial biomass of the first cut of alfalfa, compared to the control. In general, the neutralising substances applied caused a decrease in the content of potassium in the analysed plant parts.

Keywords: fluorine, substrate contamination, potassium content, crops, neutralising substances

INTRODUCTION

Fluorine is a widespread element in nature. In fact, it is the 13th most abundant element in the Earth's crust (Ochoa-Herrera *et al.* 2009). The contamination of the natural environment with fluorine compounds has become a global problem (Czerny *et al.* 2000). Fluorine in the environment originates from natural minerals, especially fluorite, apatite, muscovite and biotite (Kinnunen *et al.* 2003). Besides, rising concentrations of fluorine in various compartments of the environment are

strictly connected with emissions of this element from phosphate fertiliser manufacturing plants, aluminium smelters, glassworks, steelworks, ceramic manufacturing plants and municipal heat and power plants (Bombik *et al.* 2011). Hydrogen fluoride (HF) released to the environment is three-fold more toxic than O₃, SO₂ or NO₂ (Weinstein and Davison 2003).

The natural content of fluorine in plants ranges from 1 to 10 mg F kg⁻¹ d.m. It should be added that different plant species demonstrate different sensitivity to fluorine compounds (Arnesen 1997, Rey-Asensio and Carballeia 2007, Vike 1999).

There are numerous investigations indicating the negative effect of fluorine on plants, adversely affecting the growth and development of plants (Joshi and Bhardwaj 2012, Saini *et al.* 2012, Telesiński *et al.* 2012), causing leaf damage (Doley 2010, Mezghani *et al.* 2005) or decreasing the content of chlorophyll in leaves (Chakrabarti *et al.* 2012, Elloumi *et al.* 2005, Gupta *et al.* 2009).

The relevant literature still lacks sufficient data to explain the influence of fluorine on the content of macroelements in plants, hence the present study, in which eight pot trials were completed to identify the influence of soil contamination with fluorine on the content of potassium in plants. Another experimental factor was the introduction of some neutralising substances to soil, such as lime, charcoal and loam, in order to limit the negative effect of fluorine on the development of plants.

MATERIALS AND METHODS

Eight greenhouse pot trials, conducted at the University of Warmia and Mazury in Olsztyn in 2009-2011, provided data for analysis. The pots were filled with soil from the arable horizon with the texture of loamy sand. The soil reaction was 5.89 in H₂O and 4.43 in KCl; the hydrolytic acidity of soil was 30.7 mmol(+) kg⁻¹. The soil contained 43.2 mg P, 124.5 mg K and 30.0 mg Mg kg⁻¹ of soil. Other determinations were: the content of organic carbon 6.0 g kg⁻¹, total nitrogen 0.62 g kg⁻¹ and total fluorine 125 mg kg⁻¹.

The test plants were: maize (*Zea mays* L.), yellow lupine (*Lupinus luteus* L.), winter oilseed rape (*Brassica napus* L.), spring triticale (*Triticosecale* Wittm.), narrow-leaf lupine (*Lupinus angustifolius* L.), black radish (*Raphanus sativus*), phacelia (*Phacelia* Juss.) and alfalfa (*Onobrychis viciaefolia* Scop.).

Two factors were analysed. The first order factor consisted of increasing doses of fluorine in the form of potassium fluoride (commercial form) which was used to simulate soil contamination. The second factor involved a comparison of three substances neutralising soil contamination with fluorine.

Soil contamination with fluorine, depending on the sensitivity of the crops to this element, was:

- 0, 20, 40 and 60 mg F kg⁻¹ of soil under sensitive plants, i.e. narrow-leaf lupine;
- 0, 50, 100 and 150 mg F kg⁻¹ of soil under moderately sensitive plants, i.e. alfalfa;
- 0, 100, 200 and 300 mg F kg⁻¹ of soil under less sensitive plants, i.e. maize, winter oilseed rape, spring triticale, black radish and phacelia.

Another species which belongs to fluorine-sensitive plants is yellow lupine which was sown as a catch crop after the harvest of maize to examine the residual effect of soil contamination with fluorine.

Regarding two trials, namely with narrow-leaf lupine and alfalfa, lower doses of fluorine were used than elsewhere because papilionaceous plants are more sensitive to the presence of various xenobiotic substances in soil.

The following were used as substances neutralising the soil contamination with fluorine: lime (in a dose corresponding to 1 Hh of soil), charcoal and loam (in amounts equal to 3% of the soil in a pot).

Apart from the neutralising substances, the soil was mixed with identical quantities of NPK mineral fertiliser in order to supply the plants' nutritional demands. Nitrogen was applied as urea in the amount of 111 mg N, phosphorus as 46% triple superphosphate in the amount of 48 mg P, and potassium as 57% potassium salt in a dose equal to 111 mg K kg⁻¹ of soil.

In total, each experiment consisted of 16 treatments with 3 replications. The above doses of fluorine, neutralising substances and fertilisers were added and thoroughly mixed with soil, after which soil batches were put into marked pots. Immediately afterwards, the test plants were sown.

While the plants were growing, the soil moisture content was maintained on the level of 60% field water capacity. The harvest was carried out at the technological maturity phase. At harvest, plant samples divided into aerial parts and roots were taken for laboratory analyses. The biomass harvested from pots was combined into aggregate samples corresponding to individual treatments. These samples were comminuted and dried at 60°C.

The concentration of potassium in the plants was determined by the atomic emission spectrophotometric method AES (Ostrowska *et al.* 1997). In alfalfa, the content of potassium was assayed only in the aerial biomass from the first cut.

The results underwent statistical processing with Statistica software (Statsoft 2010), using two factor analysis of variance ANOVA. The least significant differences (LSD) were determined at the level of significance $\alpha = 0.05$ using the Duncan test.

RESULTS AND DISCUSSION

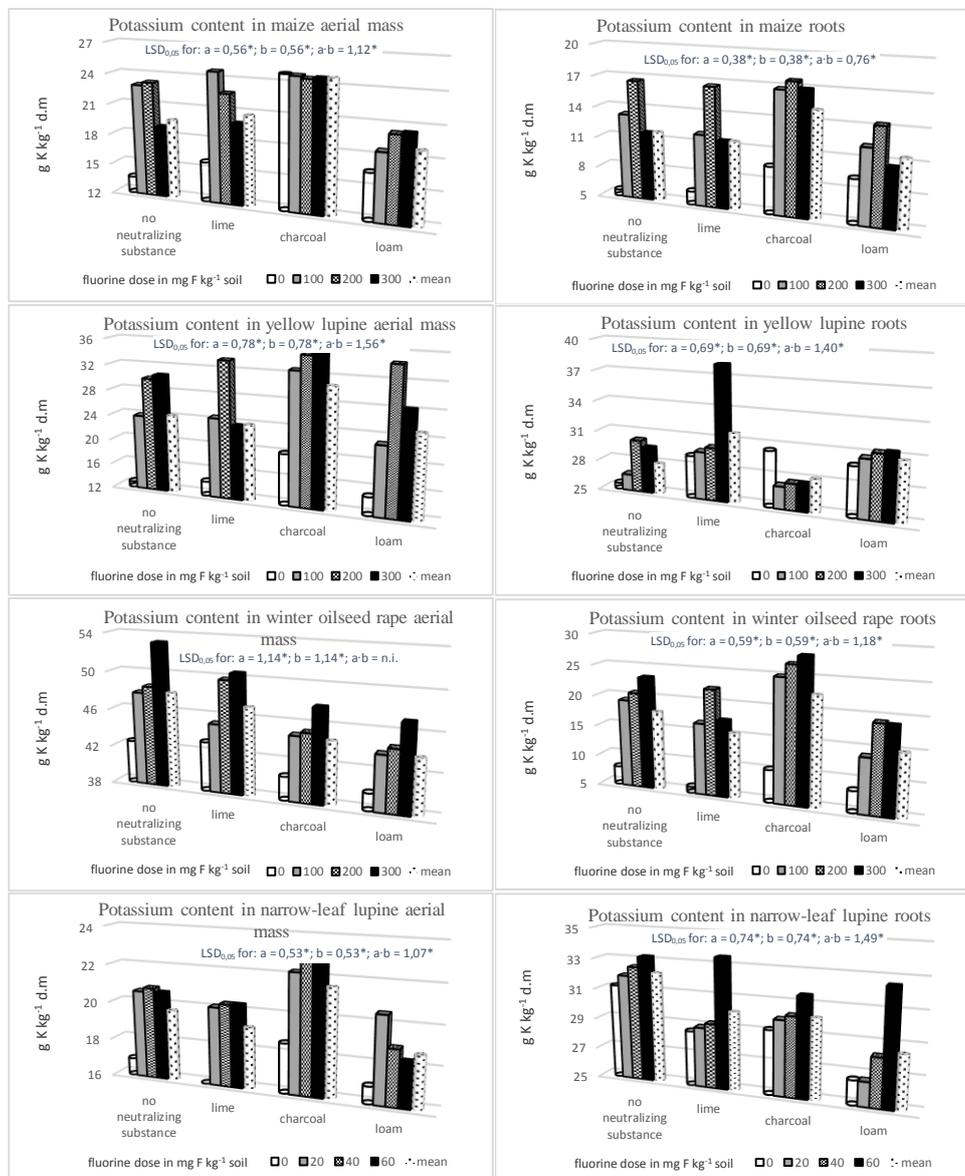
The content of potassium in the analysed plant organs depended on the soil contamination with fluorine, the applied neutralising substance and the plant species and organ (Fig. 1). The highest mean content of potassium was determined in the aerial biomass of phacelia (46.4 g K kg⁻¹ d.m.) and winter oilseed rape (45.9 g K kg⁻¹ d.m.), while the lowest one was found in the grain and straw of spring triticale (5.3 and 7.9 g K kg⁻¹ d.m., respectively). Fung and Wong (2002) tested Chinese tea and found a higher content of potassium in leaves than in roots of that plant; it varied from treatment to treatment, but always exceeded the level of 10 g K kg⁻¹ d.m. Also, in an experiment on common wheat, Maclean *et al.* (1992) found more potassium in sprouts than in roots of the plant. Pyś and Pucek (1993) showed that fodder crops grown on fields adjacent to the Phosphate Fertiliser Production Plant in Machów were characterised by a high content of potassium, with its peak concentration recorded in leaves of fodder beet.

In our experiment, higher levels of potassium in all test plants were determined in the series without any substance neutralising the soil contamination with fluorine.

The highest degree of soil contamination with fluorine, i.e. 60 mg F kg⁻¹ of soil in the series with narrow-leaf lupine, 150 mg F kg⁻¹ of soil in the experiment with alfalfa and 300 mg F kg⁻¹ of soil in pots cropped with the other plants, had a stimulating influence on the content of potassium in the plants. Thus, the highest increase in the concentration of potassium in plant tissues was determined in roots of winter oilseed rape (190%), yellow lupine roots (136%), spring triticale straw (129%) and maize roots (107%).

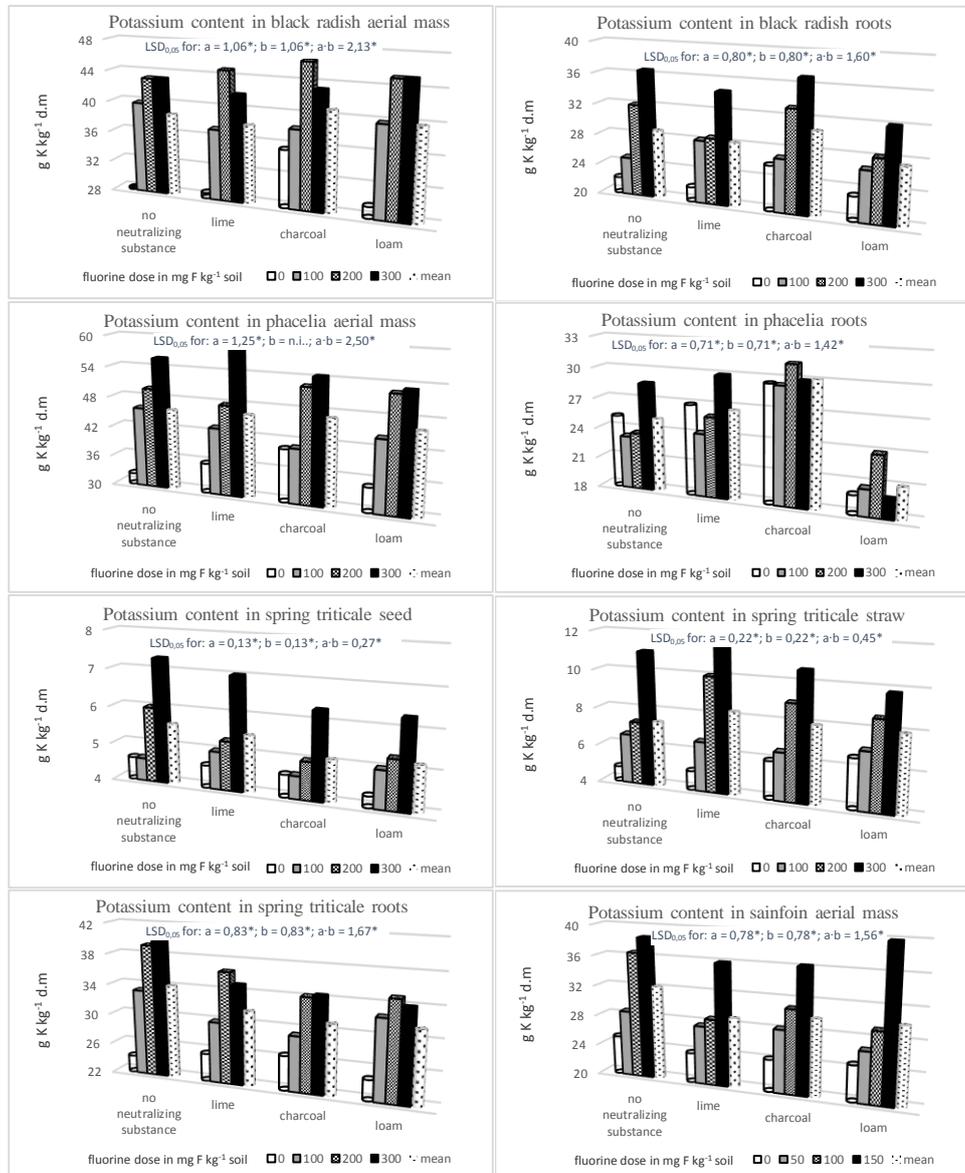
Noteworthy is the highest, almost three-fold increase in the content of potassium in maize roots after the application of the medium fluorine dose, i.e. 200 mg F kg⁻¹ of soil. An extremely large increase in the content of this macroelement was also noted in roots of winter oilseed rape affected by any of the applied fluorine doses. The concentration of potassium in oilseed rape roots, relative to the uncontaminated pots, was 141, 158 and 190% higher under the effect of the growing fluorine doses. Positive correlations between the soil contamination with fluorine and the content of potassium in Chinese tea plants were also demonstrated by Ruan *et al.* (2004).

Phacelia was an exceptional plant, as the content of potassium in its roots decreased, by 8 and 6% relative to the control, under the influence of the lowest and medium fluorine doses, i.e. 200 and 300 mg F kg⁻¹ of soil, respectively. A similar tendency was mentioned by Li and Ni (2009) in their experiment on Chinese tea, where a decrease in the content of potassium was observed against the increasing doses of fluorine.



a – fluorine dose; b – type of neutralising substance; * p – significant for 0.05

Fig. 1. Concentration of potassium in analysed plants depending on soil contamination with fluorine and neutralising substance applied



a – fluorine dose; b – type of neutralising substance; * p – significant for 0.05

Fig. 2. Concentration of potassium in analysed plants depending on soil contamination with fluorine and neutralising substance applied

The impact of increasing soil contamination with fluorine on the content of potassium in plants was modified by adding to the substrate certain substances inactivating fluorine (Fig. 1).

In most treatments, these substances caused a decrease in the content of potassium determined in the harvested biomass of the analysed plants.

All the substances applied to inactivate fluorine had a negative effect on the content of potassium in the aerial mass of winter triticale, with the strongest limiting effect produced by loam which caused an average 9% decline relative to the series uncontaminated with fluorine. However, the content of potassium in roots of the same plant increased by 27%. A decrease in the concentration of potassium was also noticed in spring triticale, whose straw had 2% less potassium in the limed series and 9% less potassium in the series with charcoal. In the roots of this plant, the potassium content declined by 7% in the series with lime up to 9% in the series with loam. All the substances neutralising fluorine decreased the content of potassium in narrow-leaf lupine roots, from 6% (charcoal) to 11% (loam). With respect to the first cut of alfalfa, lime had the strongest limiting effect on potassium content which fell by 10% relative to the control.

In general, lime used to inactivate fluorine in soil caused a decrease in the potassium content of the analysed plants. The negative effect of lime on the potassium content was the strongest in roots of winter oilseed rape, in which a 13% decrease in the concentration of this macroelement was detected versus the control. A slightly smaller decrease in the potassium content was determined in the aerial mass of alfalfa, where it equalled 10%; a 7% decrease was observed in roots of spring triticale and narrow-leaf lupine.

Out of all the neutralising substances tested, charcoal had the strongest positive effect on the potassium content in the analysed plants. Its introduction to soil contributed to an increase in the average potassium content by 26% in aerial parts and by 29% in roots of maize, by 27% in aerial mass of yellow lupine and by the same percentage in the roots of winter oilseed rape, and by 19% in roots of phacelia.

In most of the treatments, the application of loam resulted in a decrease in the average content of potassium in the analysed plants. Under the influence of this substance, a decrease in the content of potassium occurred, within the range of 4% in the aerial organs of maize to 16% in phacelia roots.

CONCLUSIONS

1. The content of potassium in the analysed plant organs depended on the species and organ of a plant, the dose of fluorine and the type of fluorine neutralising substance.

2. In response to increasing doses of fluorine, the average content of potassium in the biomass of all the test plants increased. The highest increase in the content of this macroelement, depending on the fluorine soil contamination degree, was determined after the application of the medium fluorine dose, i.e. 300 mg F kg⁻¹ of soil, where it reached 171% in winter oilseed rape roots, 113% in yellow lupine aerial mass, and 112% in maize roots.

3. The effect of lime, charcoal and loam on the content of potassium in the test plants depended on the species and organ of a plant. In general, the neutralising substances applied contributed to a decrease in the content of potassium in the examined plant parts. Compared to the control, the application of any of the tested substances caused a decrease in the potassium content in the aerial biomass of winter oilseed rape, in straw and roots of spring triticale, in roots of narrow-leaf lupine and in aerial biomass of the first cut of alfalfa.

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ODDZIAŁYWANIE ZANIECZYSZCZENIA GLEBY FLUOREM NA ZAWARTOŚĆ POTASU W BIOMASIE ROŚLIN UPRAWNYCH

Radosław Szostek¹, Zdzisław Ciećko^{1,2}

¹Katedra Chemii Środowiska, Uniwersytet Warmińsko-Mazurski w Olsztynie
Plac Łódzki 4, 10-727 Olsztyn
e-mail: radoslaw.szostek@uwm.edu.pl

²Wydział Ekologii, Wyższa Szkoła Ekologii i Zarządzania w Warszawie
ul. Olszewska 12, 00-792 Warszawa

Streszczenie. W pracy przedstawiono wyniki badań nad wpływem zanieczyszczenia gleby fluorem, do której jednocześnie dodano wapno, węgiel drzewny i il, na zawartość potasu w ośmiu gatunkach roślin uprawnych. Za podstawę badań przyjęto osiem doświadczeń wazonowych, które przeprowadzono w latach 2009-2011. W doświadczeniach uwzględniono następujące czynniki: I – wzrastające dawki fluoru w postaci fluorku potasu; II – substancje neutralizujące zanieczyszczenie gleby fluorem. Zawartość potasu była zróżnicowana w zależności od poziomu zanieczyszczenia gleby fluorem i od zastosowanych substancji inaktywujących rozpatrywany ksenobiotyk oraz od gatunku i organu badanych roślin. Najwyższą średnią jego zawartość stwierdzono w masie nadziemnej facelii – 46,4 g K·kg⁻¹ s.m. i rzepaku ozimego – 45,9 g K·kg⁻¹ s.m., a najniższą w ziarnie i słomie pszenżyta jarego odpowiednio – 5,3 i 7,9 g K·kg⁻¹ s.m. Wzrastające zanieczyszczenie gleby fluorem przyczyniło

się do wzrostu średniej zawartości potasu w kukurydzy, łubinie wąskolistnym, rzepaku ozimym, pszenżycie jarym, czarnej rzodkwi, masie nadziemnej łubinu żółtego, masie nadziemnej facelii oraz w masie nadziemnej i pokosu lucerny siewnej w stosunku do serii kontrolnej. Zastosowane substancje neutralizujące na ogół powodowały obniżenie zawartości potasu w rozpatrywanych organach roślin.

Słowa kluczowe: fluor, zanieczyszczenie podłoża, zawartość potasu, rośliny uprawne, substancje neutralizujące