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The impact of the combustion waste landfill of the Skawina Power Plant on selected elements of the agricultural production area

Artur Szwalec, Paweł Mundała, Renata Kędzior, Marek Telk, Agnieszka Lasota

University of Agriculture in Krakow, Department of Ecology, Climatology and Air Protection; al. Mickiewicza 24/28, 30-059 Krakow, Poland; e-mail: rmmundal@cyf-kr.edu.pl

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Abstract: Field observations and interviews with residents of Kopanka, Ochodza and Borek Szlachecki villages indicate that the agricultural production area located near the combustion waste landfill is negatively affected. Two distinct phenomena are observed: increased dust concentration in the air and excessive soil moisture or even flooding. The aim of the study was to assess whether and to what degree the landfill affects the content of the trace elements Cd(II), Pb(II), Zn(II) and Cu in the soil and plants of the adjoining agricultural production areas. The content of Cd(II), Pb(II), Zn(II) and Cu in the soil of the studied area was within the acceptable norms specified in the regulation of the Ministry of the Environment (Dz. U. 2002 nr 165, poz. 1359). In the herbaceous vegetation growing at sampling points W150, E150, E100 and N100, the acceptable level of Cd(II) specified in the regulation of the Ministry of Agriculture and Rural Development exceeded the norms (Dz. U. 2012 poz. 203). In turn, all the plant samples Pb(II) showed acceptable levels. The content of Zn(II) and Cu in the plant material meets the criteria for fodder proposed by IUNG (Kabata-Pendias et al. 1993). The high phytoaccumulation indices for Cd(II) and Zn(II) in the plant material may be due to dust fall containing metals. However, without precise quantitative and qualitative measurements of dust fall, it is difficult to ascertain to what extent this is caused by migration from the landfill and to what extent it is a result of deposits of pollutants from other sources.

Keywords: ash and slag mixture, heavy metals, meadow sward

INTRODUCTION

The combustion waste landfill of the Skawina Power Plant is situated on the eastern edge of the Oświęcim Basin in the Vistula oxbow lake, which is characterized by fertile soil (classes IIIa, IIIb and rarely II) and an advanced level of agricultural activity. Together with the accompanying infrastructure, it occupies an area of 68 ha. Currently, the exploited area covers 47.3 ha (the combined area of basins C-2 and C-3). Combustion waste (ash and slag mixture – 10 01 80) is relocated via the hydrotransport pipeline from the main grounds of the Skawina Power Plant to the landfill. Exploitation of the deposited waste for use in construction has recently been initiated (Referat Ochrony Środowiska Elektrowni Skawina S.A., 2012). Landfills composed of fine mineral waste from coal power plants are highly susceptible to wind and water erosion. Technical means of prevention usually do not eliminate the problem of dust pollution from this waste. Only the development of a dense vegetation cover may completely eliminate or effectively minimize water and wind erosion (Siuta 2005). A detrimental factor for environmental conditions is that, in practice, nitrogen is not present in the ash in forms available to plants, which significantly restricts the growth of vegetation. At the same time, the concentration of trace elements naturally occurring in solid fuels increases (Kabata-Pendias & Pendias 2002, Jegadeesan et al. 2008, Pandey et al. 2009). Heavy metals can be released as secondary emission from the landfill, contributing to the contamination of the soil and vegetation of the adjoining land. The agricultural production area adjacent to the landfill covers a surface of about 300 ha.

The aim of the study was to assess whether and to what degree the landfill affects the content of the trace elements Cd(II), Pb(II), Zn(II) and Cu(II) in the soil and plants of the adjoining agricultural land.

METHODS

Soil and plant samples were collected in the autumn of 2013 from meadows (currently dominant in the crop structure) situated on the western, northern and eastern sides of the landfill. The samples from the southern side were not collected, as the landscape here is characterized by severe fragmentation (the Łączany-Skawina canal, a railway line and a road), as well as by a lack of crop fields within the study area. The material for the study was collected at distances of up to 200 m (every 50 m) from a border of the landfill. Each sampling point covered an area of about 25 m^2 from which five primary samples of herbaceous plants and soil were collected. Following homogenization, they yielded an averaged sample of about 1,000 g of fresh matter (f.m.) in the case of plants and about 500 g f.m., in the case of soil. The plants were cut with scissors at the level of the soil surface, and the soil samples were collected at a depth of 0–0.03 m using a soil sampler. After air-drying, the plants were ground in a high-speed rotor mill. The soil samples were ground in a mortar and passed through a 1 mm diameter sieve. 10 g of air-dry, homogenous plant matter and 3 g of homogenous soil material were collected for analysis. The samples were weighed out with an accuracy of 0.0001 g. The material was then subjected to dry mineralization (at 460°C in a muffle furnace, with HNO_3 digestion and HCl extraction) in the case of the plants and wet mineralization (a mixture of concentrated HNO_3 and $HClO_4$), in the case of the soil (Ostrowska et al. 1991). The content of Cd(II), Pb(II), Zn(II), and Cu(II) was determined by flame atomic absorption spectroscopy in a Solaar M6 apparatus (Unicam). A phytoaccumulation index (PI) was calculated as a ratio of metal content in leaves (sward) to metal content in soil.

RESULTS AND DISCUSSION

Field observations and interviews with residents of Kopanka, Ochodza and Borek Szlachecki villages indicate that the agricultural production area where the landfill is situated is negatively affected by two phenomena: increased dust concentration in the air and excessive soil moisture, or even flooding. These affect approximately 300 ha of grassland, arable land and fallow land situated within these localities. An effective method for reducing the dissemination of airborne dust from landfills is their reclamation (Siuta 2005, Zieliński 2007, Dyguś & Madej 2012). In the case of the landfill described here, there are no detailed data concerning such reclamation, but differences in the floristic composition of the vegetation growing on the slopes of the landfill suggest that attempts at rehabilitation have been made in the past. There are woody plants growing downwind of the westerly winds usually occurring in this region. These were probably planted in order to protect residents' homes and fields from airborne dust (Szwalec et al. 2013).

Meadow sward was chosen as the plant material for the study, because it is widely available and used as feed for livestock. Moreover, due to the floristic composition of grassland sward, its biodiversity, reliability and comparability of the results of experiments conducted, it is widely used in monitoring the content of heavy metals in the environment (Czyż et al. 1996, Terelak et al. 1997, Kabata-Pendias & Pendias 2002). Cadmium content in the grasses ranged from 0.16 $mg \cdot kg^{-1}$ to 1.51 $mg \cdot kg^{-1}$ of dry matter (d.m.). In the soil, it ranged from 0.12 to 1.42 $mg \cdot kg^{-1}$ d.m. (Tab. 1). In a study conducted on this landfill, Szwalec et al. (2013) found a lower range of cadmium content in both herbaceous plants 0.1–0.62 $mg \cdot kg^{-1}$ d.m. and soil material 0.3–0.53 $mg \cdot kg^{-1}$ d.m.

Table 1
Lead, zinc and cadmium contents in soil and plants collected in the vicinity of the Skawina Power Plant combustion landfill

Location	Metal content in soil [mg·kg^{-1} d.m.]				Metal content in plants [mg·kg^{-1} d.m.]				Phytoaccumulation index (PI)			
	Cd (II)	Pb (II)	Zn (II)	Cu (II)	Cd (II)	Pb (II)	Zn (II)	Cu (II)	Cd (II)	Pb (II)	Zn (II)	Cu (II)
W200 m	0.52	20.21	85.45	10.21	0.30	1.60	23.40	1.50	0.58	0.08	0.27	0.15
W150 m	0.84	24.92	88.93	12.20	1.51	2.00	41.60	6.60	1.80	0.08	0.47	0.54
W100 m	0.65	31.12	91.42	12.24	0.96	2.50	28.00	3.50	1.48	0.08	0.31	0.29
W50 m	1.42	38.21	152.31	20.41	0.29	1.30	20.90	2.40	0.20	0.03	0.14	0.12
N200 m	0.86	24.14	148.24	34.12	0.68	2.24	24.62	4.70	0.79	0.09	0.17	0.14
N150 m	0.98	21.13	87.91	19.47	0.73	3.13	38.70	3.60	0.74	0.15	0.44	0.18
N 100 m	1.08	26.41	64.23	20.23	1.27	2.60	41.40	3.40	1.18	0.10	0.64	0.17
N 50 m	1.29	31.52	85.26	23.12	0.16	1.12	11.22	4.10	0.12	0.04	0.13	0.18
E 200 m	0.56	21.30	63.74	8.30	0.34	1.63	27.96	3.10	0.61	0.08	0.44	0.37
E 150 m	0.18	9.50	59.81	17.40	1.49	2.25	44.70	4.90	8.28	0.24	0.75	0.28
E 100 m	0.12	32.50	79.14	7.00	1.27	2.50	47.80	3.20	10.58	0.08	0.60	0.46
E 50 m	0.13	15.70	89.23	60.30	0.19	1.05	17.25	2.60	1.46	0.07	0.19	0.04

Kabata-Pendias et al. (1993) report that the average concentration of cadmium in grasses ranged from 0.01 to 3.32 mg·kg^{-1} d.m., with a mean content of 0.12 mg·kg^{-1} d.m. According to Gorlach & Gambuś (2000), on the other hand, the range is 1–5 mg·kg^{-1} d.m. Wowkonowicz et al. (2011) report that the range for this element in meadow sward sampled in the vicinity of Warsaw was much higher, from 1.93 to 3.90 mg·kg^{-1} d.m. As the herbaceous plants analysed may be a potential food source for wildlife and livestock, the results of the analyses can be compared with the acceptable norms specified in the directive of the Ministry of Agriculture and Rural Development regarding undesirable substances in animal feed (Dz. U. 2012 poz. 203). The maximum acceptable concentration of cadmium in fodder material of plant origin is 1 mg·kg^{-1} d.m. This means, that the herbaceous vegetation at the sampling points W150, E150, E100, N100 (Fig. 1) does not meet the requirements. On the other hand, it should be noted that the cadmium concentrations in the soil samples did not exceed the maximum of 4 mg·kg^{-1} d.m. given in the directive of the Ministry (Dz. U. 2002 nr 165, poz. 1359).

The conditions of trace elements migration in the soil-plant system are analysed with the use of phytoaccumulation indices (PI), which describe the plant's ability to uptake metals from the soil (Łaszewska et al. 2007). Cadmium had a phytoaccumulation index ranging from intermediate (1 ≤ PI > 0.1) to high (PI > 1) (Tab. 1). The values for $PI_{Cd(II)}$ at individual sampling points were high: 1.80 (W150), 1.48 (W100), 1.80 (N100) and 1.46 (E50). It should be noted, however, that the $PI_{Cd(II)}$ values for E100 (10.58) and E150 (8.28) are 'extremely high' – practically unprecedented in the literature (Łaszewska et al. 2007, Szwalec & Mundała 2012). During a dry year, like 2013, due to the lack of rainfall rinsing the surface of plants, dust containing cadmium may have remained on the vegetation during the study period. However, because domestic and field animals consume such 'dust-covered' feed, such vegetation was analysed in the study.

The lead concentrations in the plants analysed ranged from 1.05 to 3.13 mg·kg^{-1} d.m. These values are higher than those found by Szwalec et al. (2013) in herbaceous plants growing on the landfill (0.5–2.8 mg·kg^{-1} d.m.). In the soil of the studied area, lead content ranged from 9.5 to 38.21 mg·kg^{-1} d.m. These concentrations did not exceed the acceptable norms given in the directive of the Ministry of the Environment (Dz. U. 2002 nr 165, poz. 1359).

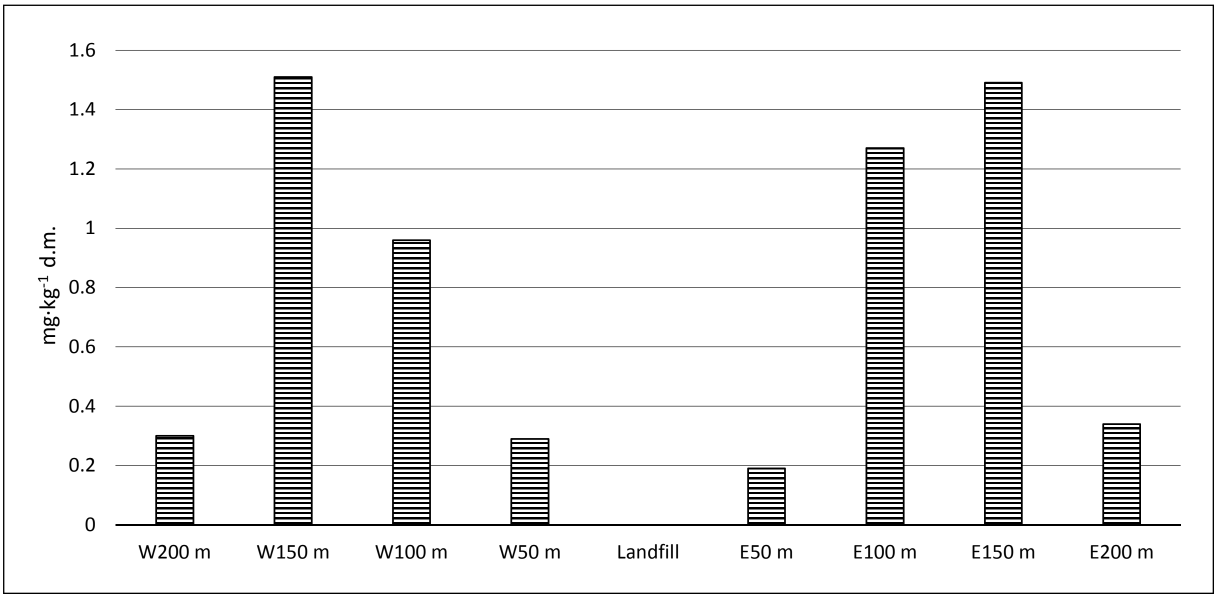

***Fig. 1.** Changes of cadmium content in the sward due to distance and exposure (west-east) on the line of prevailing winds (west)*

In soil material on the slopes and tops of the landfill, Szwalec et al. (2013) reported a comparable range (9.1–38.0 mg·kg^{-1} d.m.). The concentrations of this metal found in the plant material were lower than those reported by Madej et al. (2010), who noted a range of 1.21–14.1 mg·kg^{-1} d.m. in grasses sampled from lawns in Warsaw. In grasses from the vicinity of Warsaw, lead concentrations ranged from 3.9 to 7.5 mg·kg^{-1} d.m. (Wowkonowicz et al. 2011). Plants in the polluted areas may contain very large quantities of this metal. For example, the lead concentration in grasses was 63–232 mg·kg^{-1} d.m. in mining locations or areas with mineral deposits in Great Britain, 229–2714 mg·kg^{-1} d.m. on metallurgical industry sites in Canada and 67–950 mg·kg^{-1} d.m. on roadsides in Sweden (Kabata-Pendias & Pendias 2002). Uptake of this element from the soil by plants is limited, as the existence of a root barrier reduces its availability (Gruca-Królikowska & Wacławek 2006). According to Kabata-Pendias & Pendias (2002), critical lead concentrations for plants in the soil range from 30 to 300 mg·kg^{-1} d.m. One way that lead (as well as cadmium) weakens vegetation is by reducing biosynthesis of chlorophyll (Baycu et al. 2003). With regard to the suitability of the analysed plant material for fodder, none of the samples collected exceeded the acceptable lead concentration limits for animal feed (≤ 30 mg·kg^{-1} d.m) (Dz. U. 2012 poz. 203).

As in the case of cadmium, an increase in lead content in the sward was also noted at distances of 150 and 100 metres to the west, east (Fig. 2) and north (here also at a distance of 200 m). The scale of this increase, however, is considerably smaller than in the case of cadmium. i.e. 60–80% rather than 600–700%. Most of the plant samples collected also had low phytoaccumulation of this element – PI ≤ 0.1 (Tab. 1). Intermediate values were obtained only for sampling points E150 (PI = 0.24) and N150 (PI = 0.15).

Zinc content in the plant material ranged from 11.22 to 47.8 mg·kg^{-1} d.m., while the range in the soil was 59.81–152.31 mg·kg^{-1} d.m. (Tab. 1). As this metal is one of the most dispersed in the environment, the range for the plants (17.7–67.2 mg·kg^{-1} d.m.) and soils (45.8–161.0 mg·kg^{-1} d.m.) covering the slopes and top of the landfill is comparable (Szwalec et al. 2013). In areas unaffected by pollutants, zinc content in plants ranges from 10 to 70 mg·kg^{-1} d.m. (Pyś 1999). A similar range (12–72 mg·kg^{-1} d.m.) was reported by Kabata-Pendias & Pendias (2002) as characteristic for grasses in Poland. A considerably higher range of values for grasses growing along expressways (75.57–340.83 mg·kg^{-1} d.m.) was reported by Niesiobędzka & Krajewska (2007). The Minister of Agriculture recommendation for animal feed (Dz. U. 2012 poz. 203) does not specify acceptable values for zinc. Therefore, assessment of the grasses as potential fodder was based on the values proposed by the Institute of Soil Science and Plant Cultivation (IUNG) (Kabata-Pendias et al. 1993). i.e. 100 mg·kg^{-1} d.m. The samples collected at all the sampling points meet this criterion (Tab. 1). With regard to the soil, all of the collected samples contained acceptable amounts of this metal according to soil quality standards (Dz. U. 2002 nr 165, poz. 1359).

As in the case of cadmium and lead, an increase in zinc content was observed in the analysed sward at E100, E150 and W150 (Fig. 3) and N150. The amplitude of these changes was not, however, as great as in the case of cadmium, but more comparable to the changes in the content of lead. It should be remembered, that zinc is one of the trace elements essential to plant growth, and its concentration in the tested plants was within the range of normal physiological values (Ruszkowska & Wojcieska-Wyskupajtys 1996). The phytoaccumulation index of zinc in the grasses analysed was uniformly at an intermediate level (0.1 < PI ≤1) (Tab. 1).

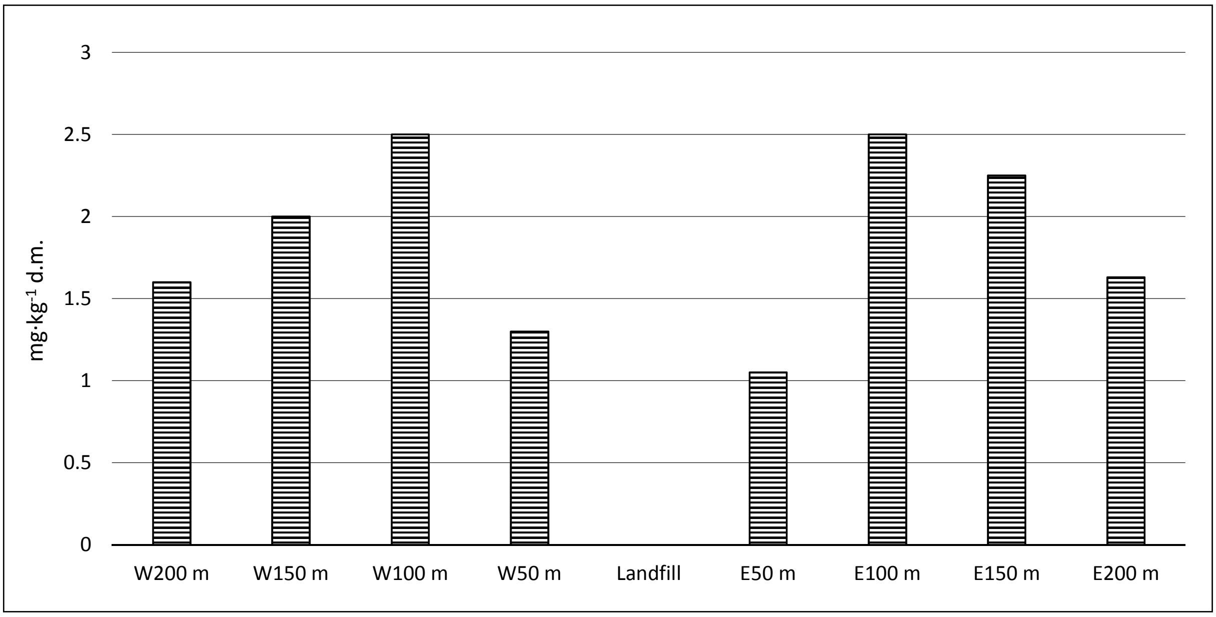

Fig. 2. *Changes of lead content in the sward due to distance and exposure (west-east) on the line of prevailing winds (west)*

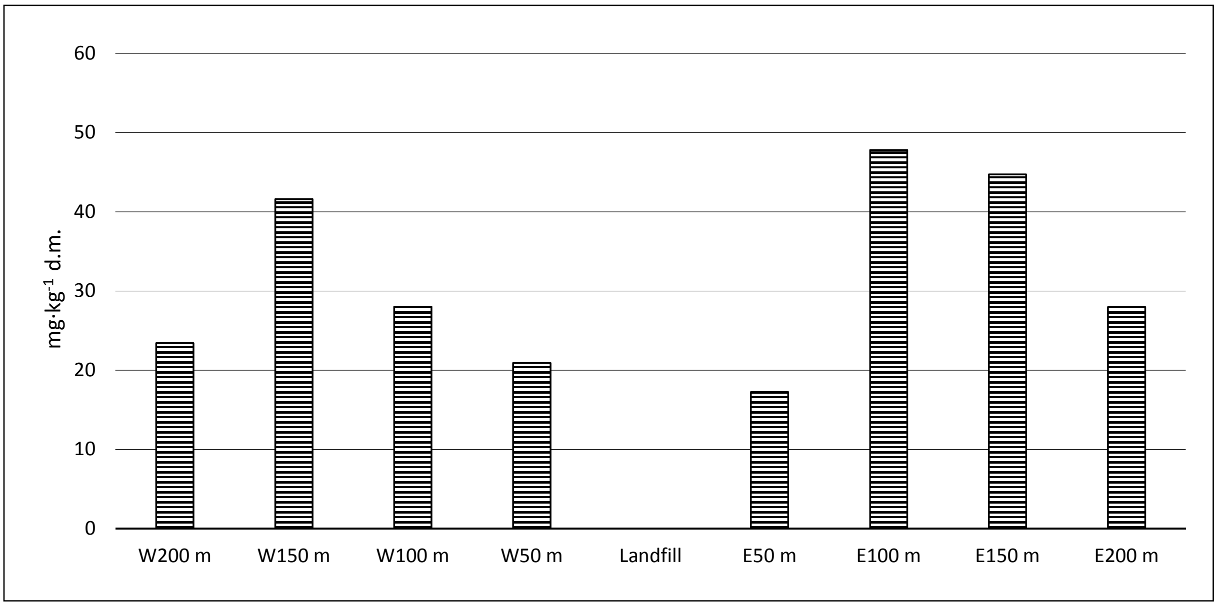

Fig. 3. *Changes of zinc content in the sward due to distance and exposure (west-east) on the line of prevailing winds (west)*

Concentrations of copper in the plant material ranged from 1.5 to 6.6 mg·kg^{-1} d.m. and in the soil from 7.0 to 60.3 mg·kg^{-1} d.m. A bit higher ranges were reported by Szwalec et al. (2013) for plants growing on the landfill (1.8–8.1 mg·kg^{-1} d.m.) as well as the soil covering it (6.6–74.5 mg·kg^{-1} d.m.). According to Kabata-Pendias & Pendias (2002), copper content in the grasses of Poland ranges from 0.6–60 mg·kg^{-1} d.m. In grasses growing along local roads in the Szczecin-Poznań corridor, Maciejewska et al. (2007) found copper concentration ranging from 2.7 to 8.8 mg·kg^{-1} d.m. A comparable range of this element (3.25–8.75 mg·kg^{-1} d.m.) was reported by Wowkonowicz et al. (2011) in the vegetation of permanent grasslands in the vicinity of Warsaw. The concentrations determined in the analysed plants were several times lower than the maximum acceptable content of this element in plants used for animal fodder (50 mg·kg^{-1} d.m.) according to IUNG (Kabata-Pendias et al. 1993). This suggests, that all of the tested plants meet this criterion. A similar relationship is found in the case of copper content in the soils of the study area. All of the samples had substantially lower levels of this metal than the acceptable concentration of 150 mg·kg^{-1} d.m. specified by soil quality standards (Dz. U. 2002 nr 165, poz. 1359). As in the case of cadmium at sampling points W150 and E150, the copper content was substantially higher than at the other points (Fig. 4).

Copper also had a low (0.04 at E50) or intermediate (the 11 remaining sampling points), degree of phytoaccumulation (Tab. 1). In analysing the copper concentration in the sward samples it should be considered whether content below 3 mg·kg^{-1} d.m. (sampling points W200, W50 and E50 – Tab. 1) illustrates a deficiency of this element (Ruszkowska & Wojcieska-Wyskupajtys 1996). The field observations conducted during the study indicate that factors other than the airborne dust and flooding mentioned by the residents, which in their opinion originate in the landfill, contribute to the degradation of the agricultural environment of this area.

While dissemination of dust from the landfill was indeed observed during the study, flooding may also originate in drainage ditches, a long-neglected element of the infrastructure. These ditches have not undergone conservation for many years. This is conducive to water stagnation, particularly during the spring and autumn and after heavy rainfall, which also directly affects the yield and quality of the crops grown here. An additional negative factor is the progressive degradation of the vegetation in the area. Each year, there is more and more fallow land, which becomes a habitat for weeds and pests. Such neglected fields, besides posing a 'biological' threat, are also a fire hazard. They are sometimes burnt in the spring and autumn creating a significant threat not only to the crops, but also to the people and their properties.

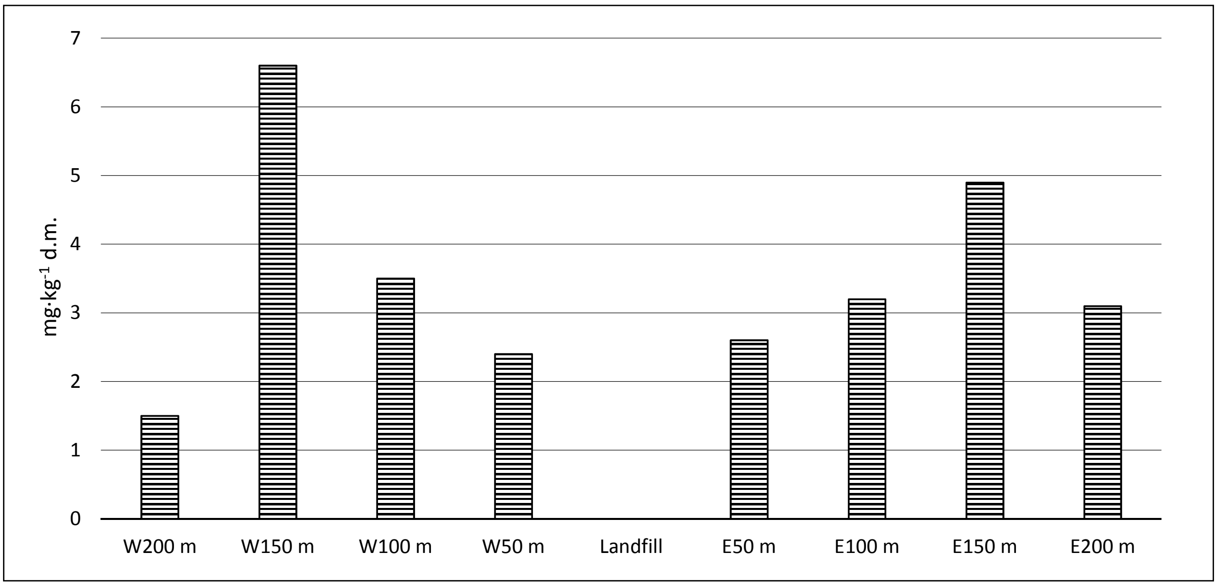

***Fig. 4.** Changes of copper content in the sward due to distance and exposure (west-east) on the line of prevailing winds (west)*

Unauthorized dumps appear on fallow land situated near temporary roads, additionally exacerbating the degradation of the area. Due to the composition of the waste deposited here, these dumps pose a serious threat to the soil and water environment and to the fauna of the area.

CONCLUSIONS

1. In the herbaceous plants growing at sampling points W150, E150, E100 and N100, the acceptable level of Cd specified in the directive of the Ministry of Agriculture and Rural Development was exceeded (Dz. U. 2012 poz. 203).
2. All of the plant samples Pb(II) were within the acceptable levels specified in the directive of the Ministry of Agriculture and Rural Development (Dz. U. 2012 poz. 203).
3. Content of Zn(II) and Cu(II) in the plant material meets the criteria for fodder proposed by IUNG.
4. Content of Cd(II), Pb(II), Zn(II) and Cu(II) in the soil of the area studied was within the acceptable norms specified in the directive of the Ministry of the Environment (Dz. U. 2002 nr 165, poz. 1359).
5. The high phytoaccumulation indices value for Cd(II) and Zn(II) in the plant material may be due to dust fall containing metals. However, without precise quantitative and qualitative measurements of dust fall, it is difficult to ascertain to what extent this is caused by transmission from the landfill and to what extent it is a result of deposits of pollutants from other sources.
6. Degradation of the agricultural production area may also be affected by neglected drainage ditches and by fallow land, of which the area increases each year by the burning of it as well as by the expansion of unauthorized rubbish heaps.

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