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Evaluation of Off-site Effects of Wind-eroded Sediments Especially the Content of Pesticides

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Abstract

Wind-eroded sediment, as an environmental transport pathway of toxic elements and pesticids, can result in environmental- and human exposure far beyond the agricultural areas where it has been applied. In our research we quantified the pesticide residues moving in the soil near Szeged (Hungary) on the original soil surface of agricultural areas with a portable wind tunnel. Before the experiments, a portion of the sample area was treated with chlorpyrifos and pendimethalin. A control area was also selected. In 2017-2019, a total of 42 wind event experiments were conducted by examining the topsoil samples. During the experiments, moving soil particles were trapped at various heights (5-10 cm, 20-25 cm and 50-55 cm) and the pesticide concentrates by GC-MS were measured. The enrichment ratios (ER) were calculated, and statistical analyzes were also carried out (SPSS). The measurements obtained that the pendimethalin ER is much higher in the rolled fraction (mean: 13.7) than chlorpyrifos (mean: 2.9). Our measurements showed that the enrichment of chlorpyrifos and pendimethalin can be detected in the rolling and suspended soil particles.

Keywords: wind erosion; chlorpyrifos; pendimethalin; wind tunnel experiment

Introduction

Due to the frequency of extreme weather events (extreme rainfall, drought) associated with climate change, furthermore intensive soil use, inadequate agricultural cultivation and agrotechniques, there has been an increase in soil deflation sensitivity. Wind erosion now poses a risk not only to sandy soils, but also to degraded, dusty, fertile, chernozem soils. Cultivation can significantly accelerate wind erosion (Stefanovits & Várallyay 1992; Farsang et al. 2011; 2013; Farsang & Barta 2004; Liu et al. 2007).

At medium wind speeds, significant dust emissions have been observed in different countries of Europe (Szatmári, 1997; Gossens, 2002; Bärring et al., 2003). According to a report by the United Nations Environment Program in 1991 (UNEP), more than 46% of the total degradation of arid areas is caused by wind erosion (Zheng, 2009). According to Eurostat (Internet 4, 2018), approximately 11.4% of the EU area is affected by medium to severe soil erosion (more than 5 tonnes per hectare per year). The total annual soil loss in the EU is estimated at 950 Mt (Internet 4, 2018). Korcz et al. (2009) found that 52% of the European Union's PM10 emissions come from agriculture.

The proportion of areas affected by wind erosion is also significant in Hungary. Much of the country is covered with sand and loam soils, which are heavily exposed to deflation. More than 60% of the lowland areas are utilized as arable land, which further increases the vulnerability (Farsang, 2016; Pásztor, 2018). The annual wind speed is 2-4 m/s in the country. The highest monthly wind speed averages are during early spring (March, April) when most of the croplands are uncovered. Maximum wind speeds above 10 m/s are also often measured in April (In-

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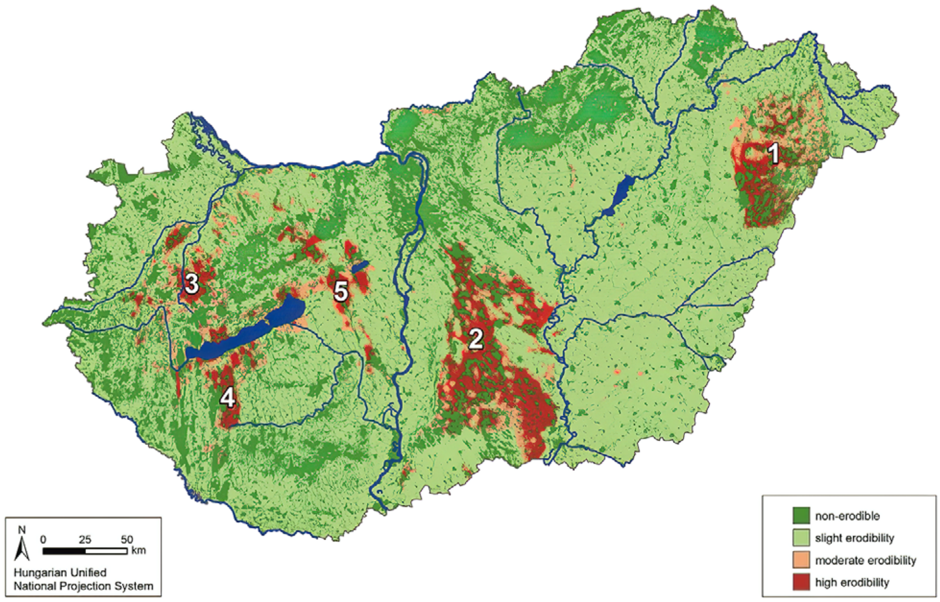

Figure 1. Wind erosion susceptibility map of the Hungarian soils. The five distinct areas: Nyírség (1), Danube–Tisza Interfluve (2), glacis in the foreground of the Transdanubian Mountains (3), Inner Somogy (4), Transdanubian loess region (5) (Pásztor et al. 2016)

ternet 2, 2016; Pásztor, 2018). According to the results of Pásztor et al. (2016), the total area affected by wind erosion in Hungary is about 10,000 km2, which is about 10% of the country's area. In their research, besides the physical diversity of soils, in addition to the wind speed of a given area, the surface cover was also used for classification (Pásztor et al., 2016; Pásztor, 2018) (Fig. 1). Bartus et al. (2019) investigated the risk of wind erosion in Csongrád County during their research. It was determined that 37.5% of the area of Csongrád County (our research area) is exposed to wind erosion every year.

The physical degradation of nutrient-rich topsoil is not the only problem. Agricultural soils account for a significant source of airborne particulate matter (PM10, PM2,5) because of wind erosion and tillage activities (Gill et al., 2006). Contaminants (heavy metals and other potentially toxic substances, for example, pesticide residues) can adhere to the surface of soil particles. So deflation can become a significant human health problem, especially for the inhabitants of settlements where arable land under intensive cultivation is dominant. The airborne particles released by the wind have a huge impact on human and animal health. Due to their size, they can easily reach the bronchial tube by inhalation, causing severe human diseases (asthma, heart and lung diseases, and also cancer) (Besancenot et al., 1997; Toy et al., 2002; Järup, 2003; Riksen, 2004; Bach, 2008; Sterk & Goossens, 2007; ; Kim et al., 2015; Internet 1). The finest particles (dust) can travel over large distances. Small particles can travel from 500 km to thousands of kilometres during moderate wind storms (Pye, 1987). The largest amounts of pesticides and heavy metals are usually adsorbed to the fine particles (Agassi et al., 1995; O'Hara et al., 2000). These contents can also be normally enriched in the fine (suspended) particles (Clymo et al., 2005). As a result, more and more studies are now being conducted on the off-site effects of wind erosion (Larney et al., 1999; Farsang et al., 2013; Bento et al., 2016; Csányi et al., 2019a, b).

Based on the results of previous canal research in this area (Szeged), it can be concluded that hummus enrichment in wind-driven sediment 1.1 (Farsang et al., 2013; Farsang et al., 2022). The humus displacement that can be registered during an erosive wide event is 5.5–6.9 g m^{-2}, the P displacement is 0.1–0.8 g m^{-2}, and the K displacement is 1.6–13.9 g m^{-2}. These values show an order of magnitude Sterk et al. (1996) with field-on-site measurement results.

Deflation processes can be well modelled with in-situ wind tunnels (Maurer et al., 2006; Farsang et al., 2022). This research study aims to evaluate the potential risks of agricultural dust using a portable wind tunnel. This study investigates the occurrence of chlorpyrifos and pendimethalin in wind-eroded sediment accrued from loess and sandy soil produced during wind erosion in wind tunnel experiments.

Materials and methods

Sample area

The study areas are located near Szeged. It's composed of Chernozem and Arenosol soils (Fig. 2). The in-situ wind tunnel studies were conducted in the summer of 2017-2019 (Fig. 3). The sample area was 20m×40m and 40×50m in 2017 and 2018 respectively. In 2019 we took ex-situ measurements, so we collected loam and sandy topsoil samples near Szeged.

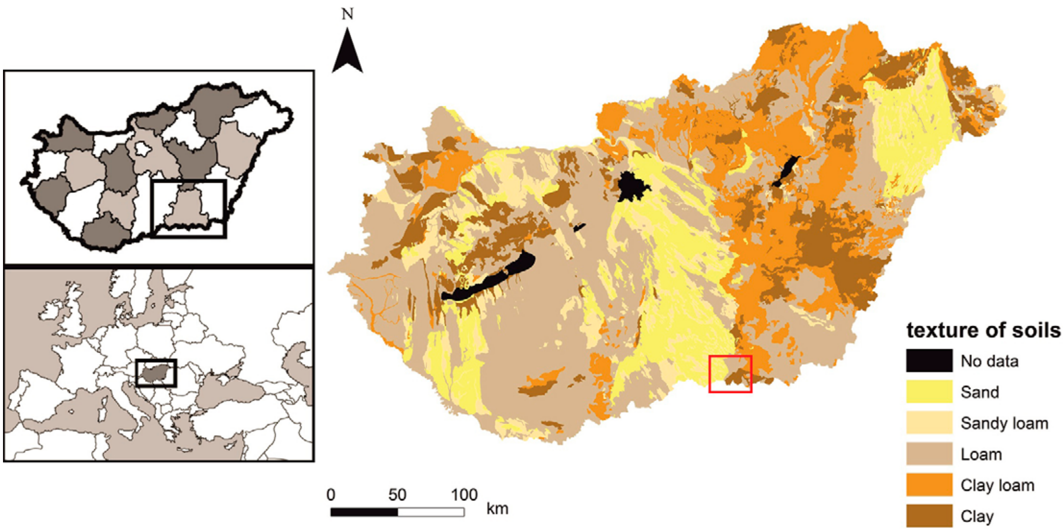

Figure 2. Location of the studied area and soil properties

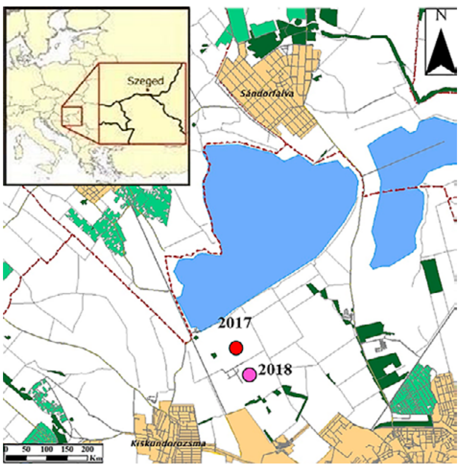

Figure 3. Sample points

Sampling and measurements

Measurement methods in 2017-2018

Two of the most commonly used pesticides in Hungary have been selected for the experiments (Internet 3., 2016). Before the experiment, a part of the sample area was treated with chlorpyrifos (2 l/ha) and pendimethalin (5 l/ha) (application rate is typically applied in agricultural fields). A control area was also selected. In the summer of 2017-2018, a total of 28 in-situ wind event tests were conducted. The undisturbed surface soil was measured in a portable and adjustable 12 m long field wind tunnel (Fig. 4) in-situ on the study plot. Each wind tunnel experiment was carried out with a duration of 10 minutes and approximately 13 ms-1 wind speed.

Wind velocity has been measured along horizontal and vertical profile lines during all experiments (Fig. 5) using a Lambrecht Jürgens 642 anemometer. The ground area blown within the wind tunnel covers 3.36 m². Samples were taken from the topsoil (0-5 cm) before and after the wind event at three different places in the wind tunnel. The rolling soil samples (sediments) were collected after each run at the end of the wind tunnel using a clean brush (Fig. 5).

Figure 4. The portable wind tunnel

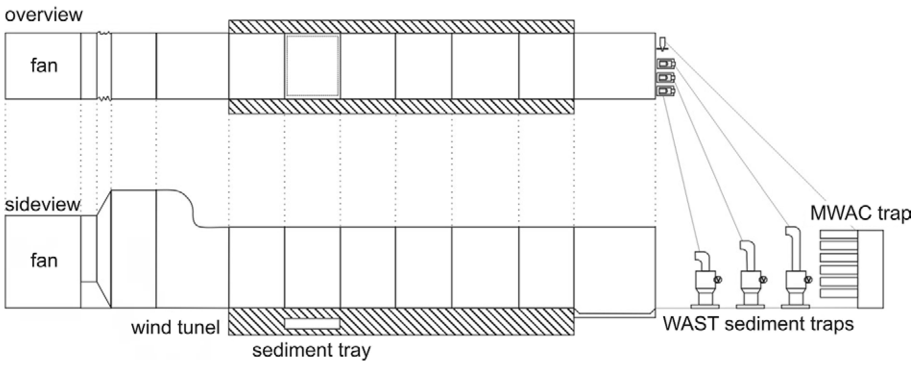

Figure 5. The location of the soil sample points, the WAST traps and the sediment traps at the end of the tunnel (Farsang et al. 2022)

Measurement methods in 2019

In the summer of 2019 14 ex-situ wind tunnel experiments were conducted (10 experiments on loam texture soil and 4 on sandy texture soil). We put on the ground a plastic sheet and an approximately 5 cm thin layer of the soil was spread on it. The soil was then sprayed with the prepared solution: pendimethalin solution was prepared by diluting Sharpen 330 EC herbicide that contains 330 g/l pendimethalin in water, chlorpyrifos solution was prepared by diluting Alligator™ insecticide that contains 480 g/l chlorpyrifos in water. The prepared soil was measured in a wind tunnel. Each deflation experiment were carried out with a duration of 10 minutes and approximately 12 ms-1 wind speed on the loam soil and 6 ms-1 on the sandy soil.

Samples were taken from the topsoil (0-5 cm) before and after the wind event at three different places in the wind tunnel. After each run, the rolling soil samples (sediments) were collected at the end of the wind tunnel using a clean brush and the suspended particles were collected by WAST (Wet Active Sediment Trap). This is a patented, horizontal, active, isokinetic, wet trap. Trap inlets are 5 10 cm, 20 25 cm, 50 55 cm high (Fig. 6). Distilled water was used for trapping. WAST samples were stored refrigerated in a borosilicate sample holder until laboratory measurement.

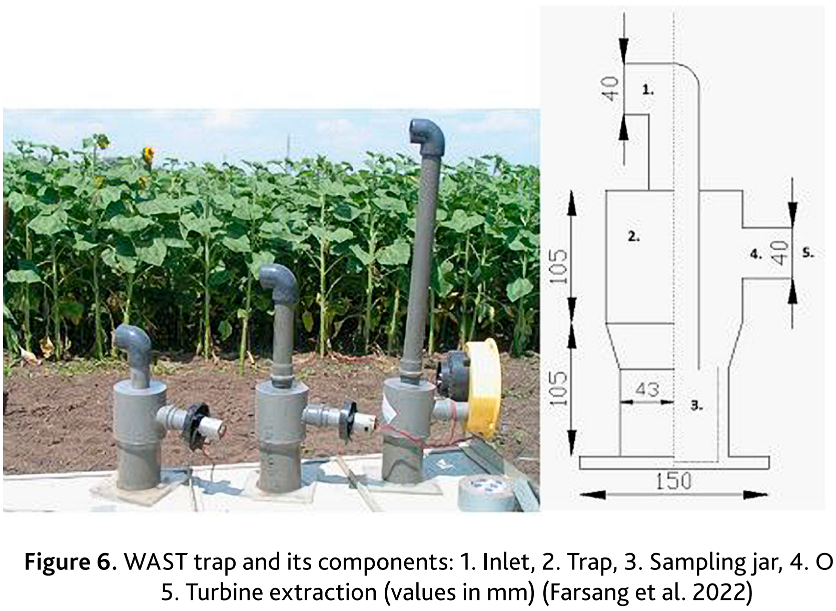

Figure 6. WAST trap and its components: 1. Inlet, 2. Trap, 3. Sampling jar, 4. Outlet, 5. Turbine extraction (values in mm) (Farsang et al. 2022)

Sample analysis

All laboratory analyses were carried out according to Hungarian standard procedures. After the appropriate preparation, the following parameters were determined: topsoil samples: (pH (H_2O)), $CaCO_3$ (%), Arany yarn test, OM %, total salt content (%), humidity (%); rolling soil samples and suspended fraction: chlorpyrifos, pendimethalin concentrations. Pesticide contents are determined by GC-MS-MS (EPA 8270D:2007 Rev.:4).

After that, the enrichment ratios (ER) of concentrations in the rolling samples were calculated (1). If the values of the enrichment factors are around 1 or less, the test component will not be enriched in the erosion-displaced sediment.

$$ER = \text{Element concentration}_{sediment}/\text{Element concentraion}_{soil} \quad (1)$$

Statistics

The statistical tests were carried out by SPSS software (IBM SPSS Statistics, Version 24). The Kolmogorov-Smirnov test was used to test the normality of all data. Spearman's coefficient was used for the non-parametric correlation analysis.

Results and Discussions

Soil properties

The topsoil sample properties are shown in Tables 1. The average humidity content was 1,44 %. The chernozem soils are characterized by a slightly alkaline pH (7.58-8.03), medium humus content (2.68-3.15%), a low to medium carbonate content (0.98-7.14 %) and a sandy loam-loam texture. No significant difference can be observed in the case of chernozem soils examined in 2017, 2018 and 2019, the observed differences do not affect the degree of wind erosion. The arenosol soil is characterized by a slightly alkaline pH (7.21), low carbonate content (1.26%) and sandy texture (Table 1.).

Chlorpyrifos and pendimethalin content in the wind-eroded sediment

Results of pesticide content in 2017

In 2017, we performed 13 wind tunnel experiments. Before the experimental run, part of the sampling area was treated with chlorpyrifos. Ten experimental runs were performed on the sprayed area and three on the control area.

The chlorpyrifos content (Fig. 8) of the treated topsoil varied between 0.004 and 009 mgkg-1. In the collected rolling soil fraction the concentration of chlorpyrifos varied between 0.014 and 0.096 $mgkg^{-1}$. The enrichment factors were calculated. These values

Table 1. Soil properties of the soil (Chernozem and sandy Arenolols) used in this study of 2017,2018 and 2019

N=28 (average)	pH (H_2O)	OM%	$CaCO_3$ (%)	Soil texture class	Total salt content (%)
Chernozem 2017	8,03	3,15	0,98	Sandy loam	0,03
Chernozem 2018	7,58	2,68	7,13	Loam	0,02
N=14 (average)					
Arenosol 2019	7,21	1,2	1,26	Sand	0,01
Chernozem 2019	7,69	3,1	7,14	Loam	0,04

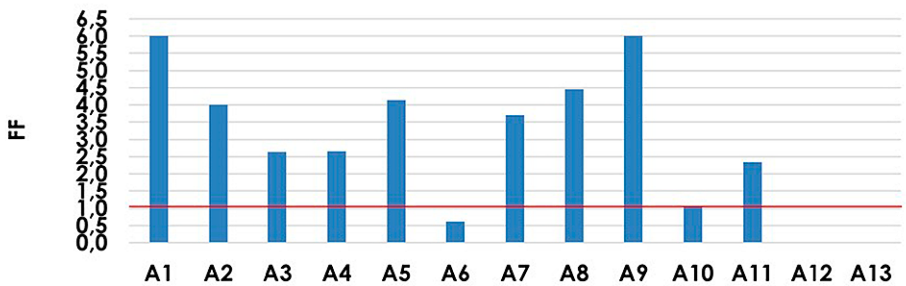

Figure 7. Chlorpyrifos enrichment ratios (ER) in the rolled sediment (A1-A11: Chlorpyrifos-treated area, A12-A13: control area)

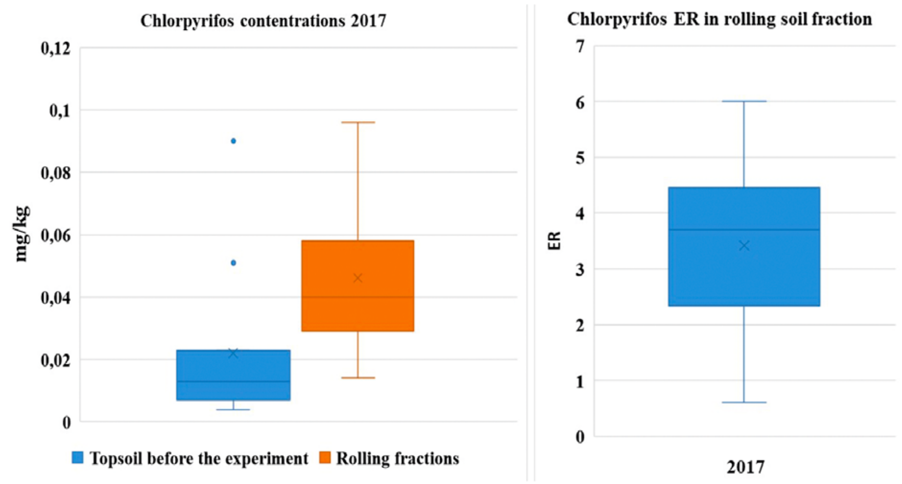

Figure 8. Results of concentration and enrichment ratio (ER) of chlorpyrifos in 2017

ranged from 0.61 to 6 (Fig. 7). No pesticide contamination and overgrowth were measured on the control plots (A12, A13). The average of the enrichment values of chlorpyrifos was 3.4 (Fig.8).

Results of pesticide content in 2018

In 2018, we performed 15 wind tunnel experiments. Before the experimental run, part of the sampling area was treated with chlorpyrifos and pendimethalin. Nine experimental runs were performed on the sprayed area and six on the control area.

The chlorpyrifos content (Fig. 9) of the treated topsoil varied between 0.01 and 0.1 $mgkg^{-1}$. In the collected rolling soil fraction the concentration of chlorpyrifos value ranged from 0.05 to 0.3 $mgkg^{-1}$. The enrichment factors were calculated. These values ranged from 0.6 to 7. The mean value of the enrichment was 2.9.

The pendimethalin concentration (Fig. 9) of the treated topsoil varied between 0.01 and 0.8 $mgkg^{-1}$. In the collected rolling soil fraction the concentration of pendimethalin varied between 0.07 and 2.1 $mgkg^{-1}$. The enrichment factors were calculated. These values ranged from 0.7 to 52,5. The average of the enrichment value of pendimethalin aswas 13.7

The results of the measurements showed that the ER of pendimethalin is much higher (ER:13,7) in the rolled fraction than ER (2,9) of chlorpyrifos.

Results of pesticide content in 2019

In the summer of 2019, we performed 14 ex-situ wind tunnel experiments on loam texture soil and 4 on sandy texture soil. Before the experimental run part of the collected soils was sprayed with chlorpyrifos and pendimethalin. Thirteen experimental runs were performed on the treated soils and one on the control soil sample.

The chlorpyrifos content of the treated loam texture soil varied between 2.03 and 23.03 $mgkg^{-1}$. In the collected rolling soil fraction the concentration of chlorpyrifos value ranged from 10.58 to 104.90 $mgkg^{-1}$. The enrichment factors were calculated. These values ranged from 0.88 to 20.85. The mean value of the enrichment factors was 4.98. The chlorpyrifos content of the treated sandy texture soil varied between 7.05 and 13.93 $mgkg^{-1}$. In the collected rolling soil fraction the concentration of chlorpyrifos value ranged from 15.01to 19.09 $mgkg^{-1}$. The values of enrichment factors ranged from 1.37 to 2.36. The mean value of the en-

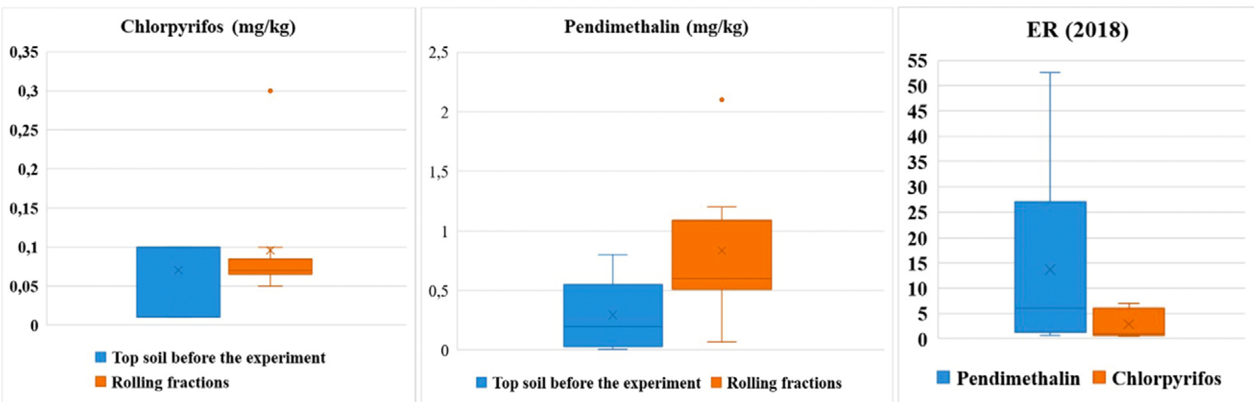

Figure 9. Results of concentration and enrichment of chlorpyrifos and pendimethalin in 2018

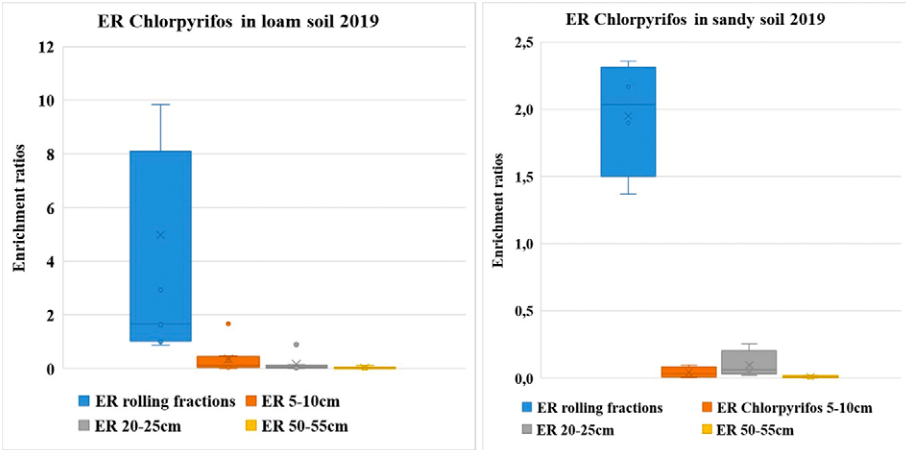

Figure 10. Enrichment of chlorpyrifos in texture of loam and sandy soil in 2019

richment factors was 1.95. In the case of chlorpyrifos-treated soil, the enrichment factor did not reach 1 in any of the suspended fractions (Fig. 10).

The pendimethalin concentration of the treated loam texture topsoil varied between 1.30 and 33.75 $mgkg^{-1}$. In the collected rolling soil fraction the concentration of pendimethalin varied between 13.60 and 358.60 $mgkg^{-1}$. In the rolling particles, the results of enrichment factors ranged from 1.51 to 42.74. The average of the enrichment values of pendimethalin was 9.01 in the samples of the rolling fractions. The average of the enrichment factor was greater than 1 at 5-10 cm too. In the case of sandy texture soil, the enrichment factor was as follows: in the rolling particles, the mean values were 2.05 (Fig. 11). The results of the measurements showed that the ER of pendimethalin is much higher in the rolled fraction than ER of chlorpyrifos.

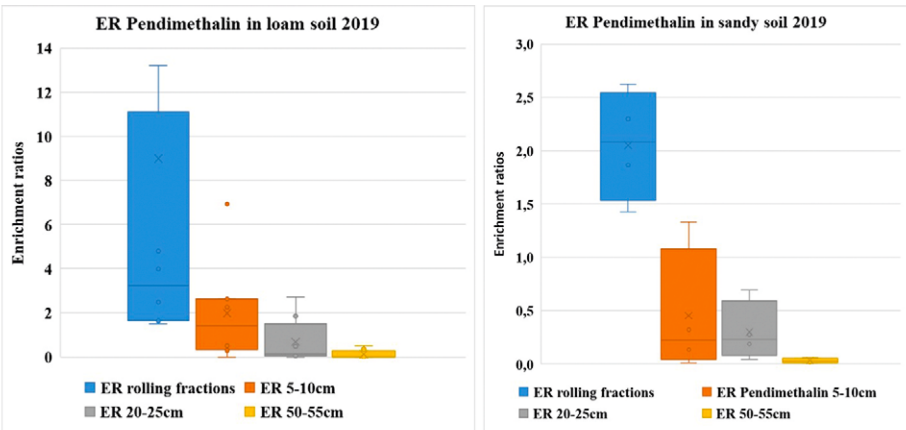

Figure 11. Enrichment of pendimethalin in the texture of loam and sandy soil in 2019

Discussion

Statistical studies were performed to explore the relationships between measured concentrations in soil and displaced sediment and enrichment factors. All statistical analyses were performed in SPSS 22. The Kolmogorov-Smirnov test was used to test the normality of all data. Because none of our data is normally distributed Spearman's correlation was computed to assess the relationship between pesticide contents. The statistical tests revealed a strong significant relationship between the pesticide's enrichment factors and the pesticide concentration of the topsoil and between pendimethalin ER chlorpyrifos ER as well ($p<0,01$) (Fig.12) (Table 2.).

Measurements in 2017 showed that the average enrichment values for chlorpyrifos were 3.4. The results of pesticide measurements in 2018 showed that pendimethalin ER was much higher in the rolled fraction (mean: 13.7) than in chlorpyrifos (mean: 2.9). Measurements in 2017, 2018 and 2019 showed that the tested pesticides were enriched in the rolled soil fraction in all measurements and in all tested plant protection products, which is due to the fact that the humus content (H%: 2.7-3.2)) ER: 1.1) is most enriched in this sediment fraction (Farsang et al., 2013; Farsang et al., 2021) and this organic colloid content is a very good binding surface for pesticides. Chernozem soils have a higher enrichment rate than sandy soils. In addition, a significant correlation can be found between the ER of chlorpyrifos and pendimethalin.

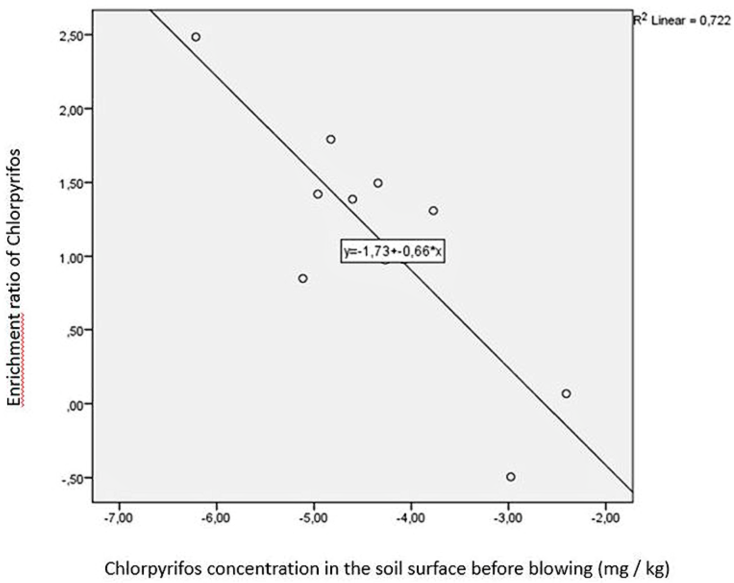

Figure 12. The connection between the Chlorpyrifos concentration in the soil surface before blowing and the ER of Chlorpyrifos

Table 2. Values of Spearmen's correlation coefficient

Spearman's rho	Chlorpyrifos topsoil	Correlation Coefficient	1,000					
		Sig. (2-tailed)						
		N	18					
	Pendimethalin topsoil	Correlation Coefficient	,951**	1,000				
		Sig. (2-tailed)	,000					
		N	18	18				
	ER Chlorpyrifos Rolling Part.	Correlation Coefficient	-,074	-,017	1,000			
		Sig. (2-tailed)	,771	,948				
		N	18	18	18			
	ER Pendimethalin Rolling Part.	Correlation Coefficient	-,219	-,177	,864**	1,000		
		Sig. (2-tailed)	,382	,483	,000			
		N	18	18	18	18		
	ER Chlorpyrifos 5-10 cm	Correlation Coefficient	-,867**	-,517	,817**	,783*	1,000	
		Sig. (2-tailed)	,002	,154	,007	,013		
		N	9	9	9	9	9	
	ER Pendimethalin 5-10 cm	Correlation Coefficient	-,850**	-,717*	,650	,683*	,917**	1,000
		Sig. (2-tailed)	,004	,030	,058	,042	,001	
		N	9	9	9	9	9	9

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed)

The results show that during each major wind erosion event the accumulation and spread of contaminants bound to the soil particles must be considered. Our results can be useful in quantifying agricultural pressures, tracking the spatial movement of materials moving by the wind (potential pollutants), and can be used in later landscape and settlement planning tasks (shelterbelts, etc.).

Conclusions

As a result of climate change, longer and longer dry periods are expected in the Hungarian Great Plain, which is favorable for wind erosion events. Therefore, it is very important to look at what the wind brings from the dry surface during such a wide-ranging event.

In this work, wind tunnel measurements were performed on Chernozem and Arenosol soils in the Southern Great Plain of Hungary. The present study aimed to investigate the pesticide contents of wind-eroded sediment. The measurements showed that the enrichment of chlorpyrifos and pendimethalin could be detected in the rolling particles. The analysed pesticides were enriched in the rolling soil fraction. As shown by our study, airborne particulates can be contaminated with chlorpyrifos and pendimethalin too.

The above experiments show that there is adequate reason to take off-site airborne transport of pesticide-contaminated soil fractions seriously, especially during sufficiently long periods of drought. The results show that during each major wind erosion event the accumulation and spread of contaminants bound to the soil particles must be considered. Our results can be useful in quantifying agricultural pressures, tracking the spatial movement of materials moving by the wind (potential pollutants), and can be used in later landscape and settlement planning tasks (in the correct choice of tillage methods and tools, direction and quality, height, etc. of shelterbelts., etc.).

The increasing use of pesticides is a worldwide trend. The consequence of climate change is that in our region, more and more drought can be expected in the early spring and summer periods. Tillage carried out under inadequate moisture conditions (the soil is too dry) causes a deterioration of the soil structure, i.e. the soil becomes dusty. The consequence of this is that the risk of deflation also increases. For this reason, monitoring and estimating exposure to airborne pesticides will be very important in the near future.

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