MICROPLASTICS IN THE SOIL PROFILE AND GROUNDWATER OF GREENHOUSE FARMLANDS OF SOUTHEAST- HUNGARY

DOI: https://doi.org/10.18509/GBP22035s
UDC: 502.521:678.5-022.53(439)

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ABSTRACT

Soil profile and groundwater under greenhouse farming are susceptible to microplastics contamination due to high generation of plastic waste. Natural and anthropogenic processes such as, infiltration, presence of cracks and farm management practices favor the vertical penetration of contaminants from the soil surface to soil depths and groundwater aquifers. In this study, we quantify and characterized the microplastics in the soil profiles and groundwater of greenhouse farmlands from Southern Hungary. We selected six soils profiles on the plots of greenhouses in the greenhouse farmlands of two cities, which have not been in use for about 3 years and 15-20 years respectively. Six soil profiles were dug, and samples were collected at intervals of 20 and 40 cm. Groundwater samples were also collected from the same profiles at a depth of 100 cm and below 4 meters. Microplastics were extracted from the groundwater by vacuum filtration process, while, predigestion of organic matter with 30%H2O2 and density separation with ZnCl2 was used to extract microplastics in the soil profile samples. Microplastic contamination was detected in the soil profile, thought; its distribution is not uniform. However, microplastics were also recorded in five of the six drilled areas, the average microplastics concentration in the groundwater was 2.5 pieces/L, and fibers were the dominant plastic structure. Given that microplastics were found in soil profiles, and groundwater, we recommend the treatment of groundwater from such areas before it is used for human consumption or irrigation as well as careful cleaning and disposal of plastics on greenhouse farmland.

Keywords: greenhouse farming, microplastic, pollution, Soil profiles, groundwater contamination

INTRODUCTION

Greenhouse farming began in 1953–1954 at the Kentucky Agricultural Experiment Station in the United States [1]. Today, greenhouse farming contributes heavily to the production of various agricultural products. Globally, greenhouse farming covers 220,000 ha of land and consumes 250,000–350,000 tons/year of plastic film [2]. Low-density polyethylene (LDPE) is the major plastics used for greenhouse coverage [2, 3-5]. Other polymer presence in the greenhouse farming includes polyvinyl chloride (PVC), ethylene-vinyl acetate, and linear LDPE [6-8]. These plastics materials are used inform of plastic pipes, fibers for tightening and plastic containers for agrochemicals. The plastics for greenhouse coverage have short time span and can easily age as a result of weather, agrochemicals, and environmental pollution [2, 3-5].

Plastic contaminants can be small-sized particles, i.e., <5 mm, referred to as microplastics. These plastic contaminants enter agricultural soils such as greenhouse and other farming sites through mulching [9], sewage sludge [10], and organic and inorganic fertilizer application [11-12]. Microplastic waste can be transferred vertically through the soils by water, microorganisms, and leaching [13-15]. Other means of transportation include irrigation and other agricultural practices, as well as cracks on the soil surface.
Plastic contaminants in the soil ecosystem affect the quality of agricultural products and the growth and photosynthesis of plants are altered by the presence of microplastics [16-19]. Furthermore, Plastic contaminants in the soil ecosystem alter soil quality and fertility by altering its structure, bulk density, and water holding capacity [20-21]. Importantly, microplastics can adsorb and transport contaminants such as heavy metals and other pollutants in the soil environment [22-23]. Therefore, the health of soil organisms and their enzymatic activities are disturbed by microplastic contamination [24]. Lastly, direct ingestion of microplastics or consumption through contaminated food, such as fish and agricultural products, is a threat to human health [25].
Moreover, there is a knowledge gap in terms of microplastic contamination in the soil profiles and groundwater of greenhouse and general soils. The current studies available on the microplastics pollution in the soils concern on the soil surface and shallow depths. Recently, the World Health Organization [26] lamented the lack of studies on microplastics in drinking water; they emphasized that although the scant data do not reveal the threat to human health, there is a need to collect more data to draw proper conclusions. Hence, the present case study aimed (1) to quantify the level of microplastics distribution and contamination in the soil profiles and groundwater on two greenhouse farmlands; (2) to examine the morphological structures of microplastic contaminants; and (3) to measure the relationship between soil depth and microplastic availability.

MATERIALS AND METHOS

Study Case

This research was conducted on the agricultural soils of greenhouse farmlands located next to Szeged and Szarvas in the south-eastern part of Hungary. Both areas were selected based on size, history of greenhouse farming. The first study area has a climatic conditions of warm and dry (mean annual temperature: 10.5 °C; mean annual precipitation: 520 mm), with 2,080–2,090 h per annum average annual radiation. The area is 84 m above sea level, and the perched groundwater depth is 100 cm. The sample area is plain with loess bedrock, and the natural soil type is Phaeozem (according to the World Reference Base for Soil Resources) [27-28]. The greenhouse area is used for tomato cultivation. Sampling occurred in March 2021. In total, 20 soil samples were collected from the soil profiles. Additionally, three shallow groundwater samples were collected.
The second area is located in Szarvas. The climatic condition is warm and dry (mean annual temperature: 10.2 - 10.4oC; mean annual precipitation: 520 mm), with 190 - 810 h as an annual average radiation. The area is 82.6 - 92.1 m above sea level, and the perched groundwater depth is 2-4 m. The sample area is plain with infusion loess bedrock, and the natural soil type is Chernozem [29]. The greenhouse area was established in 1990s and is abandoned since 2007. The area was used for tomatoes, pepper and cucumber production. The sampling occurred in February 2022. In total, 27 soil samples were collected from the soil profile and three shallow groundwater samples were also collected.

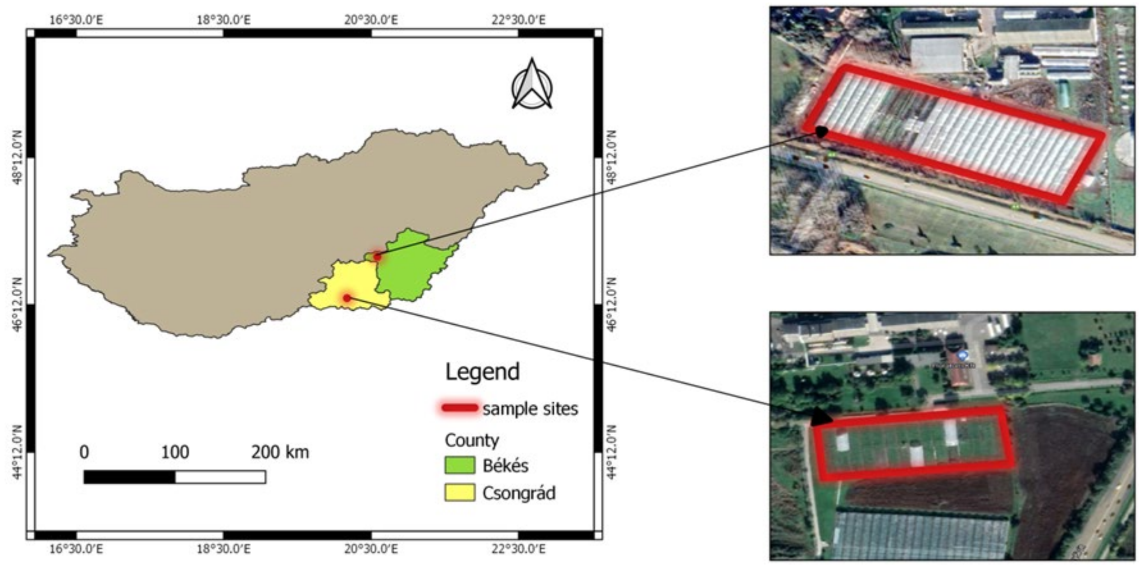

Figure 1. Map of the study area

Sampling from the soil profiles

For the first area, three boreholes were drilled in the middle of each sampling plot to collect samples from the soil profile. The samples were obtained at 20 cm intervals from the surface to where the effects of groundwater were clearly observed; the three profiles had depths of 160, 140, and 140 cm, respectively. For the second area, random sampling method was used to select three areas. Three boreholes were similarly drilled in the middle f each sampling plot. Profile 1 has a depth of 70 cm and samples were collected at the 20 cm interval. Profile 2 and 3 have depths of 4 and 5 meters respectively; thus, samples were collected at every second layers (i.e., 0-20, 40-60, 80-100, 120-140 cm).

Sampling from the groundwater

Groundwater in area 1 was reached at 160, 120, and 120 cm respectively. The perched groundwater was collected at the depth of 100 cm reach. However, Groundwater in area 2 was reached at the depths of 70 cm, 4 meters and 5 meters respectively. While the perched water level were 40, 350 and 450 cm for the respective profiles.

Microplastic sample preparation

To obtain pure plastic debris, a method developed by Li et al [30], which was modified and adjusted by Saadu and Farsang [31], was used. Briefly, the soils were oven-dried at 40°C and sieved with a 5 mm sieve. In 250 mL conical flasks, 10 g of soil was mixed with 40 mL of 30% H2O2, and 10 mL of Fenton reagent for organic matter digestion. The solutions were heated at 70°C until they had dried up. The flask containers were then immersed in cold water and a few drops of butyl alcohol were added to reduce the samples spout out. ZnCl2 [1.5g/cm3 (5mol/L)] was used as a flotation salt and 40 mL of the solution was added. The complete solutions were capped with aluminum foil and shaken for 1 h at 200 rpm in an orbital shaker, after which they were emptied into 100 mL beakers and allowed to settle for 24 h. Approximately 20mL of the upper supernatants were collected with a glass pipette, and 20mL of ZnCl2 was added to the solution, which was shaken for 30 min in the orbital shaker for a second time. The upper supernatants were again collected and combined with the first supernatants to form single microplastic extracts. These extracts were later filtered through a nylon membrane filter (20 µm) and

Whatman filter (0.45 μm), respectively, using a vacuum pump. The filters were air-dried and taken to the laboratory for microscopic microplastic identification and quantification. The suspected plastic particles were confirmed using a needle and heat method and Raman spectroscopic analysis.

Identification, classification, and quantification of plastics

The extracted microplastics were observed using an Inspex II microscope (software version: 1.06; film ware version: F001-001-011; ring light version: 1.03; Ireland) at 50× magnification. Some suspected microplastics particles were confirmed using the heat and needle method. These experiments were conducted at the analytical laboratory of the Department of Geoinformatics, Physical and Environmental Geography, University of Szeged. Pieces of different macroplastics and 5% of the suspected microplastics were later confirmed using a Raman spectrometer. Obtained Raman spectra were compared with the Raman library; thus, the compositions of plastic materials were accurately determined. Raman analysis was performed at the Department of Mineralogy, Geochemistry, and Petrology, University of Szeged.

Statistical analysis and quality control

Both descriptive and inferential statistics were used in this analysis. Descriptive statistical analysis was performed using Microsoft Excel, whereas inferential analysis was conducted using SPSS (version 22). The relationship between microplastics and soil depth was determined using Spearman's rank correlation. ANOVA was used to determine the relationships among soil profiles. A bare minimum of plastic materials was used during sampling and laboratory analysis. Contamination prevention techniques, such as rinsing the apparatus with distilled water three times, were adopted throughout the laboratory processes, during which a cotton lab coat and hand gloves were always worn by researchers. To prevent atmospheric contamination, aluminum foil was used from sampling until the final stages to cover the analyzed samples.

RESULT AND DISCUSSION

Abundance of microplastics in soil profiles and relationship with soil depth

The abundance of microplastics was extensively studied in the soil profile of two areas. One-way ANOVA revealed that in area 1 and 2, there were no significant differences among the three profiles in terms of microplastic availability in the soil horizon [$F(1, 2) = 0.59$, $P > 0.05$)]. Individual profile analysis revealed that the distribution of microplastic particles was not uniform. The individual profiles analysis in area 1 is as follows; profile 1 has the highest concentration (200 pieces/kg) of MiP in the 100-120cm layer followed by 40-60 cm, 120-140 cm and 140-160 cm where 100 pieces/kg were respectively recorded. According to Spearman's correlation analysis, there was a moderate positive correlation between depth and microplastic content in this profile, but it was not statistically significant [$r(8) = 0.626$, $P = 0.097$]. Profile 2 has the highest concentration of 300 pieces/kg in the 80-100 cm layer followed by 0-20 cm with MiP concentration of 200 pieces/kg. There was a weak negative correlation, which was not statistically significant, between depths and microplastic content [Spearman's correlation: [$r(6) = -0.235$, $P = 0.653$]. In profile 3, the highest concentration of 300 pieces/kg was recorded in 40-60 cm layer followed by 0-20 cm with 200 pieces/kg. There was a strong negative correlation between depth and microplastic content, which was not statistically significant [$r(6) = -0.759$, $P = 0.080$].

Similarly, in area 2, the individual profiles were also extensively analyzed. For profile 1, the highest concentration of 500 pieces/kg was recorded in the 20-40 cm layer, followed by 0-20 cm with 300 pieces/kg. According to Spearman's correlation analysis, there was a moderate negative correlation between depth and microplastic content in this profile, but it was not statistically significant [r(4) =-0.316, P =0.684]. Similarly, Profile 2 has the highest concentration of 300 pieces/kg in the 0-20cm layer followed by 200 pieces/kg in 20-40 cm. According to Spearman's correlation analysis, there was a moderate negative correlation between depth and microplastic content in this profile, The relationship is not statistically significant [r(10) =-0.555, P =0.096]. Also, Profile 3 has the highest concentration of 400 pieces/kg in 0-20 and 40-60 cm layers respectively, followed by 100 pieces/kg in 80-100 cm layer. According to Spearman's correlation analysis, there was a strong negative correlation between depth and microplastic content in profile 3[r(13) =-0.697, P =0.008]. The relationship is statistically significant.

These results agree with previous findings on the penetration of microplastics at different soil depths from 0 to 80cm [32]. Moreover, the vertical distribution of soil microplastics from the surface to the soil horizon occurred as a result of soil texture, the dry–wet nature of the soil, agricultural activities (e.g., plowing and harrowing), leaching of irrigation water, and transportation of microplastics by soil microorganisms through their various activities [13, 15, 20, 32-34]. Taken together, these findings imply that the presence of microplastics deep in the soil could contaminate underground and soil aquifers over time.

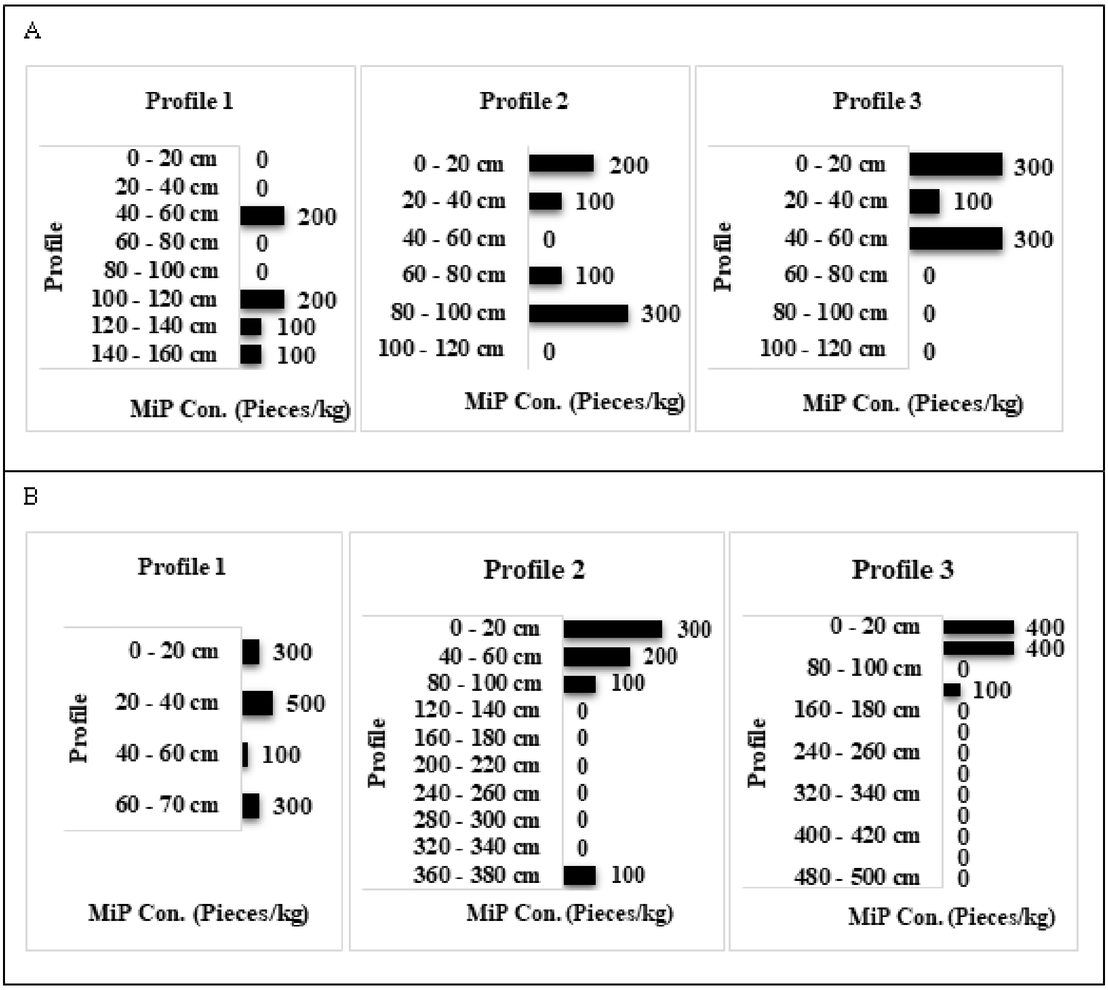

Figure 2. Abundance of microplastics in the soil profiles; A (Area 1) & B (Area 2).

Abundance of microplastics in groundwater

Figure 2 reveals the abundance of microplastics in groundwater. In area 1, microplastics were recorded in two of the three drilled areas (not in Drilling 3). The average concentration of microplastics in the groundwater was 3.3pieces/L. In Drilling 2, the highest number of microplastics recorded was five particles, whereas that in Drilling 1 was three particles. Contrarily, the average concentration in area 2 (Szarvas) is 2.6 pieces/L. In Drilling 1, the highest number of microplastics recorded was five, whereas two and three microplastics particles were respectively recorded in Drilling 2 and Drilling 3. The difference in MiP content in the areas was tested with One-way ANOVA. The result revealed that there were no significant differences among the two areas in terms of microplastic availability in the groundwater [$F(1, 4) = 0.14$, $P > 0.05$)]. The result of presence of microplastics in the groundwater are consistent with some findings on microplastics in groundwater. For example, Su et al [35] found a few microplastic fibers in the Jiaodong Peninsula, China, and Panno et al [36] reported 15.3 particles/L in karst groundwater. Our results also support the hypothesis of Wanner [37], who assumed that deposition of plastics in agricultural areas could contaminate the groundwater and soil aquifers beneath agricultural farmlands. However, our finding differs from that of Panno et al [36] in terms of the wide gap in the number of microplastics; this could be attributed to differences in soil texture and climatic conditions (amount of rainfall) as well as the openness of the surface water, which makes it prone to atmospheric surface runoff and other environmental contaminants. Our results are also in agreement with previous postulations that microplastics can penetrate the soil and contaminate the groundwater and aquifers through infiltration and other contamination sources [38, 13]. Additionally, cracks in the soil might act as pathways for microplastic contamination to the groundwater. Taken together, these result simply that groundwater is prone to microplastic contamination. Hence, microplastics could potentially be consumed directly in some areas where groundwater is used as drinking water without undergoing proper treatment.

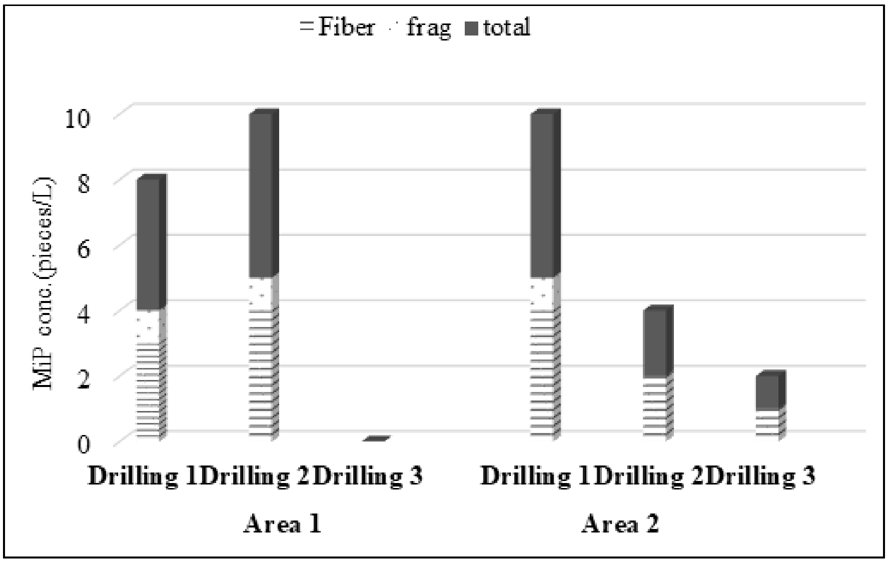

Figure 3. Microplastics abundance in groundwater of two areas

However, the result of the morphological structures of the plastics contaminants is revealed in Table 1. The table shows that fibers and fragments were found in the farmlands. Fiber microplastics are predominantly available in the areas. Panno et al. [36]

and Su et al [35] similarly reported fibrous materials to be the main contaminant structures in Illinois, USA, and in Jiaodong Peninsula, China, respectively. The availability of fibrous contaminants in the areas may occurred as a result of wide spread of fibrous materials in areas. Also, it may be as result of easiness of fibrous plastics to penetrate the soil depth through water penetration as revealed by previous researches. Furthermore, the result of two areas tally in terms of structures, as fiber and fragment were both found in the farmlands. The colors recorded in the groundwater of area 1 is black and blue while in area 2 three colors were recorded, these are; white, red, & blue, (Tble 1). The main cause of difference is attributed to the numerous varieties of macroplastics contaminants as can be observed in area 2.

Table 1: Characteristics of microplastics in the groundwater of Area 1 and 2

Sample ID	Actual Depth (cm)	Perched Depth (cm)	GPS Coord.	MiP (No.)		Total (No/L)	Color
				Fiber	Fragment		
$D_1$1	160	100	N451728.64292, E 201021.2364	3	1	4	Red & black
D_1 2	120	100	N461728.61988, E 201020.7858	4	1	5	Red & black
D_1 3	120	100	N461728.5093 E201019.8282	0	0	0	
Total						**9**	
D_2 1	70	40	767136 / 168718	4	1	5	White, blue, & Red
D_2 2	400	350	767149 / 168713	1	2	3	Blue
D_2 3	500	350	767159 / 168718	1	0	1	Blue
Total						**9**	

CONCLUSIONS

This study is among the first group of studies to quantify and characterized microplastic contamination in soil profiles and groundwater of greenhouse farmlands. Moreover, the level and distribution of microplastic contamination in the soil profiles were determined, and microplastics were found in some layers of soil profile. Microplastic particles were also found in the groundwater of greenhouse farmlands (mainly fibers). Hence, groundwater from such areas must be treated before human consumption and use in irrigation to reduce the microplastic load in the human body and agricultural soils, respectively. Additionally, farmers and stakeholders must take greater care to clean and dispose of plastics in greenhouse farming areas. Finally, this research provides insights that could lead to further research on microplastic contamination in the soil profile and groundwater.

Aknowledgement:
We thank the owners of the Flóratom Kft. (Szeged) and greenhouse farmland at Szarvas for granting us access to their respective farmlands. We also acknowledge the effort of Dr. Károly Barta, Mako Laszlo and Gabor who helped with the fieldwork during this research. Lastly, we thank Dr. Krisztián Fintor of the Department of Mineralogy Geochemistry and Petrology University of Szeged for his assistance with Raman spectroscopy analysis.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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