Current Science
CS 5 (4), 3607-3616 (2025)
Received 15 April 2025 | **Revised** 14 May 2025 | **Accepted** 13 June. 2025 | **Online Available** 16 July 2025
https://doi.org/ 10.52845/CS/2025-5-4-23

Current Science

Current Science

OPEN ACCESS

ISSN(O)2795-8639

Original Article

Characteristics and Risk Assessment of Microplastics in Farmland Soil in Kashgar, Xinjiang

Zhi-xin Mo[1], Liang-huan Wei[1], Yi-wei Dong[2]

[1]College of Chemistry and Environmental Science, Kashi Unversity, Kashi 844006, Xinjiang Uygur Autonomous Region, China

[2]Xinjiang Biomass Waste Resources Technology and Engineering Center, Kashi Unversity, Kashi 844006, Xinjiang Uygur Autonomous Region, China

[*]Corresponding Author: Zhi-xin Mo

Abstract:
This study investigates the characteristics and pollution risks associated with microplastic contamination in farmland soil within Kashgar City. Soil samples were collected from corn fields, cotton fields, greenhouses constructed in 2012, and greenhouses built in 2022, specifically from a depth of 0-30 cm. The saturated NaCl solution density separation method was employed alongside micro-Fourier transform infrared spectroscopy to extract and analyze microplastics present in the soil samples. The analysis focused on the abundance, color, morphological characteristics, particle size distribution, and types of components of microplastics found in the farmland soil of Kashgar City. Subsequently, the PLIn model was utilized to conduct a pollution risk assessment of microplastics, clarifying the associated risk levels. This research aims to elucidate the occurrence and migration characteristics of microplastics in the soil environment, thereby providing a scientific basis for the management of soil microplastics. The findings indicate that: (1) Microplastics in the farmland soil exhibit various forms, predominantly film-like and fibrous (>60%); their color is primarily transparent (>50%); and most particles are less than 200 μm in size, with polyethylene (PE) being the predominant material. (2) The microplastic pollution load index for cornfields in Kashgar City indicates mild pollution, categorized as level I, while the cotton field and greenhouse soils exhibit moderate pollution, reaching level II. Overall, the degree of microplastic pollution in the farmland of Kashgar City is assessed as moderate, corresponding to risk level II.
Keywords: soil microplastics; risk assessment; Kashgar City, Xinjiang

1. Introduction

Soil provides necessary nutrients for plant growth, and soil pollution must be taken seriously[1]. Microplastics are defined as plastic particles with a size of less than 5 mm found in the environment. As emerging organic pollutants, the presence of microplastics in soil environments has garnered significant attention[1-3].These particles originate from plastics through fragmentation processes, which include ultraviolet radiation, tillage, and windy weather conditions. Microplastics pose a considerable concern due to their ongoing contamination of soil, stemming from various sources such as residual agricultural plastic film, wastewater irrigation, sewage sludge, and fertilizer application[4-6]. Consequently, soil serves as a crucial reservoir for microplastics within the terrestrial environment [7-8]. Once introduced into the soil, microplastics can persist and accumulate over extended periods, ultimately impacting soil organisms[9]. Furthermore, since microplastics can function as carriers for various toxic contaminants, the transfer of these contaminants into the soil environment may also inflict harm on the soil ecosystem[10-11], leading to adverse effects on soil health and function.

Microplastics, pose a significant threat to agricultural ecosystems and food safety. Xinjiang, critical dryland region in China, faces pressing issue with microplastic accumulation due extensive use of mulching film[12]. China is the world's largest producer of plastic films. In 2019, China's plastic film output was 19.578 million t, from which the yield of agricultural mulching film was 2.4695 million t. The mulching area today exceeds 25 million hm^2, accounting for 61% of the global agricultural mulch film coverage[13] . Plastic mulching in China is mainly practiced with cotton planting, in Northwest China. Xinjiang is the largest cotton planting base of Northwest China, where plastic mulch is most commonly used. In 2019, the total area of plastic mulch planting in the farmland of Xinjiang was about 3.8531 million hm^2, with an average annual plastic film usage of about 235 000 t[14].

A large amount of plastic residual film remains in fields and is decomposed into secondary microplastics through the action of light, temperature, agricultural activities, soil microorganisms, etc. It is the main source of microplastics in soil[15] . The soil environment is complex and due to the lack of standardized microplastics separation and sampling methods, it is difficult to extract microplastics samples from the soil. This has resulted in a lack of research on the distribution form and abundance characteristics of microplastics in long-term mulched farmlands[16] . Singh[17] identified that the primary regions utilizing agricultural mulch films are predominantly located in Asia, particularly in India and China. Chen[18] reported that the dimensions of residual mulch film in soil can vary from nanometers to centimeters, with residual quantities ranging from several kilograms to hundreds of kilograms per hectare. This residue is primarily found in arid or semi-arid regions where the application of mulch film is prevalent. Research indicates that northwest China experiences the most severe mulch residue pollution, with average residue levels ranging from 136.7 to 259.1 kg/hm^2, and reaching as high as 502.2 kg/hm^2 [19]. In contrast, Wuhan, China, has reported a significantly lower concentration of microplastics in the soil, with only 320 to 12,560 particles per kilogram [20].

The accumulation and distribution of microplastics in agricultural soil have emerged as a significant issue of widespread concern. For instance, Cheng Wanlil found that the abundance of microplastics in dryland farmland soil in northwest China ranges from 5.80 × 10^2 to 1.19 × 10^4 microplastics per kilogram of soil (n·kg^{-1}) [21] . Zhang reported on the abundance of soil microplastics in the irrigated agricultural production area of Southwest China, noting a range of 7.10 × 10^3 to 4.30 × 10^4 n·kg^{-1}. The study also examined the distribution and predominant form of these microplastics, which was identified as fiber[22]. Liu investigated the abundance (1-754 n·kg^{-1}), distribution (white, size between 0.1 mm and 0.5 mm), and traffic impact of microplastics in agricultural soil along the river[23]. Studies have reported that the abundance of microplastics in agricultural soil on the Qinghai-Tibet Plateau ranges from 47.9 ×10^3 to 2.80 × 10^3n·kg-1[24-26]. Several studies indicate that plastic pollutants in agricultural soil across China exhibit significant diversity. For instance, fiber and white plastic pollution constitute over 70% of the soil in facility agriculture in Beijing[27], while black microplastics make up 80% of farmland soil in Guizhou, China[28]. In the dryland rice fields and orchard soils of Shaanxi, granular plastics with a particle size less than 0.5 mm account for more than 75% of the soil composition[29]. In Hubei, China, agricultural soil predominantly contains microplastics in the form of fragments smaller than 0.5 mm[30].In the agricultural soil of southern Xinjiang, film-like plastics represent as much as 91%[31]. In the rice and fish breeding soil of Shanghai, plastics with particle sizes under 1 mm constitute 52%, with polyethylene (PE) being the most prevalent type, accounting for 61%[32]. Additionally, PE microplastics comprise 50% of the forest soil in Xishuangbanna, Yunnan, China[33].

Studying the distribution characteristics of microplastics in such farmland soils can help to reveal the source of microplastics, changes that occur under mulching conditions, and better understand the ecological significance of mulching. This could provide an ecological assessment reference for global agricultural mulching areas.

2. Materials and Methods

2.1. Sample Collection

Soil samples were collected from cotton and corn farmland in Jiashi County, Kashgar City, Xinjiang, as well as from greenhouses constructed in 2012, 2017, and 2022. The sampling was conducted using the "snake-shaped point distribution method" in each designated area, and samples were obtained from the top 0-30 cm layer of soil.

2.2. Experimental Method

2.2.1 Separation and Extraction of Microplastics

Microplastics in soil samples were isolated and extracted using a saturated zinc chloride density centrifugation method. Initially, the soil sample was ground and passed through a 2 mm sieve. After drying to a constant weight, 50 g of the sample was placed into a 500 ml flask containing 150 ml of saturated zinc chloride solution (density of 1.6 g/cm³). The mixture was stirred magnetically for 30 minutes and allowed to stand overnight. The supernatant was then vacuum filtered using a nitrocellulose filter (diameter 47 mm; pore size 5 µm), and all material on the filter was transferred to a 200 ml flask. To this, 100 ml of 30% hydrogen peroxide (analytical grade) was added and mixed thoroughly. The flask was sealed with aluminum foil and left undisturbed for three days. Following this period, the digestion product was vacuum filtered, and the inner wall of the filter was rinsed multiple times to ensure that all target substances were transferred to the filter membrane. After suction filtration, the filter membrane was placed in a glass petri dish and sealed for storage. A microscope was used to analyze, observe, and photograph the microplastics, documenting their color, shape, and size. Additionally, a Fourier transform infrared spectrometer was employed to identify the material composition of the microplastics[34].

2.2.2 Identification and characterization of microplastics

The filter membrane containing microplastics was examined using a stereomicroscope (SMZ25, Nikon), where the color, size, and shape of the microplastics were meticulously recorded. Subsequently, the samples underwent analysis with a micro-Fourier transform infrared spectrometer (HYPERION2000, Bruker) to perform spectral analysis. This involved conducting a qualitative assessment of the target objects by comparing their infrared spectra with standard reference spectra. Additionally, a scanning electron microscope (SEM, Zeiss Supra55VP) was employed to observe the microplastics and their surface micromorphology.

2.2.3 Microplastic Risk Assessment Methods

A pollutant load index model was employed to assess the overall pollution level of soil microplastics, using the abundance of microplastics at various sample points within the study area as the primary indicator. The evaluation model is defined by formulas (1) to (3).

$$CF_i = C_i / C_{oi} \tag{1}$$

$$PLI_n = \sqrt{CF_i} \tag{2}$$

$$PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times \dots\dots \times PLI_n} \tag{3}$$

In the formula, CFi is the pollution coefficient of microplastics; Ci is the measured abundance of plastics; Coi is the reference value of microplastic abundance. Select the safe concentration without effect on organisms (540 pieces·kg) estimated by Everaert et al. using a mathematical model)[35], *PLIn* is the microplastic pollution load index of sampling point n; *PLIzone* is the microplastic pollution load index of basic farmland. When *PLIn* <1, the pollution level is mild pollution, 1≤*PLIn*≤2 is moderate pollution, and *PLIn*>2 is severe pollution.

2.3 Data Analysis and Processing

The abundance of microplastics in the soil samples from this experiment is expressed in units of "kg^{-1}", with the experimental results presented as mean ± standard deviation. Statistical analyses were conducted using Excel 2010 for preliminary data processing, while one-way analysis of variance (ANOVA) and multiple comparisons (LSD) were performed using SPSS 25.0. Data visualization was accomplished using Origin 2021 software.

3. Results and Discussion

3.1 Microplastic Abundance Characteristics

The abundance characteristics of soil microplastics in various types of farmland in Kashgar, Xinjiang, are illustrated in Fig. 1. The microplastic abundance in the soil of a greenhouse established in 2012 is 1498 pieces·kg^{-1}, which is greater than the abundance found in cotton field soil at 1140 pieces·kg^{-1}. In comparison, the abundance of microplastics in the soil of a greenhouse established in 2017 is 824 pieces·kg^{-1}, while the abundance in the soil of a greenhouse established in 2022 is 798 pieces·kg^{-1}.

Additionally, the microplastic abundance in cornfield soil is 514 pieces·kg^{-1}. These findings indicate that longer greenhouse cultivation periods are associated with higher microplastic abundance in the soil, and that the abundance in cotton field soil surpasses that of cornfield soil. Microplastics have been identified in farmland soil across various regions in China, including Shanghai, Shaanxi, Shandong, Liaoning, Sichuan, and the Loess Plateau, particularly in areas with a history of using mulching films. The concentration of microplastics can reach as high as 12,650 pieces·kg-1, with evidence suggesting that their abundance in farmland soil tends to increase with the duration of film mulching practices[36]. Additionally, microplastics have also been found in farmland soil that has a history of sludge agricultural use and organic fertilizer application in Spain and southwest China, with reported abundances of (960±420) pieces·kg-1 and between 7,100 and 42,960 pieces·kg-1, respectively[37]. The abundance of microplastics in Kashgar farmland soil is lower than the average abundance of microplastics in the 0-30cm soil layer in Xinjiang cotton fields (1615±5 pieces·kg^{-1})[38].

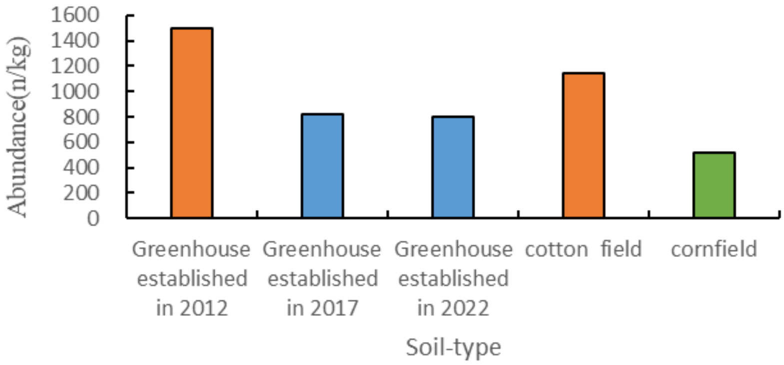


Fig 1 Microplastic abundance characteristics

3.2 Morphological Characteristics of Microplastics

Figure 2 illustrates the various shapes of microplastics found in farmland soil in Kashgar, which include film, fiber, granular, and other forms such as blocks, sheets, foams, and rods. In 2012, film-shaped microplastics constituted 46.67% of the microplastics in greenhouse soil, while fibrous microplastics made up 21.33%, granular microplastics accounted for 8.00%, and other shapes represented 24.00%. By 2017, the percentage of film-like microplastics in greenhouse soil decreased to 42.86%, whereas fibrous microplastics increased to 28.57%, granular microplastics fell to 4.76%, and other shapes accounted for 23.81%. Overall, the predominant shape of microplastics in greenhouse soil for both 2012 and 2017 was film-like. In 2022, the distribution shifted again, with film-like microplastics comprising 25.00% of the greenhouse soil, fibrous microplastics at 40.00%, granular microplastics at 10.00%, and other shapes at 25.00%, indicating that fibrous microplastics became the dominant form. In cotton field soil, film-shaped microplastics accounted for 49.12%, fibrous microplastics for 22.81%, granular microplastics for 7.02%, and other shapes for 21.05%, with film-shaped microplastics being the predominant type. In another assessment, film-shaped microplastics represented 23.08%, fibrous microplastics 42.31%, granular microplastics 7.69%, and other shapes 26.92%, confirming that fibrous microplastics were the main shape in this context. This conclusion is basically consistent with the results of the study on microplastic morphology in the northwest region[39].

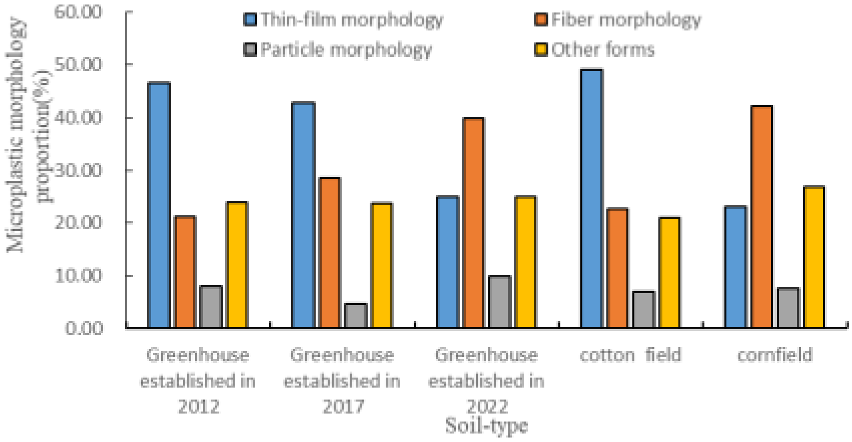


Figure 2 Morphological characteristics of microplastics

3.3 Microplastic Color Characteristics

Figure 3 illustrates the various colors of microplastics found in agricultural soil, including transparent, black, brown, red, and other hues. In greenhouse soil samples from 2012, transparent microplastics comprised 70.67%, black microplastics accounted for 13.33%, brown microplastics represented 6.67%, red microplastics made up 2.67%, and other colors constituted 6.67%. By 2017, the proportions shifted slightly, with transparent microplastics increasing to 73.81%, black microplastics decreasing to 11.90%, brown microplastics falling to 4.76%, red microplastics at 2.38%, and other colors rising to 7.14%. In 2022, transparent microplastics accounted for 65.00%, while black microplastics were 12.50%, brown microplastics decreased to 2.50%, red microplastics rose to 5.00%, and other colors significantly increased to 15.00%. In cotton field soil, transparent microplastics constituted 49.12%, black microplastics were 15.79%, brown microplastics accounted for 8.77%, red microplastics made up 5.26%, and other colors represented 21.05%. In cornfield soil, transparent microplastics comprised 65.38%, with black microplastics at 3.85%, brown microplastics at 11.54%, red microplastics at 7.69%, and other colors at 11.54%. In summary, transparent microplastics are the predominant color observed in these agricultural soils. This conclusion is consistent with the research results in northern Xinjiang cotton fields[40].

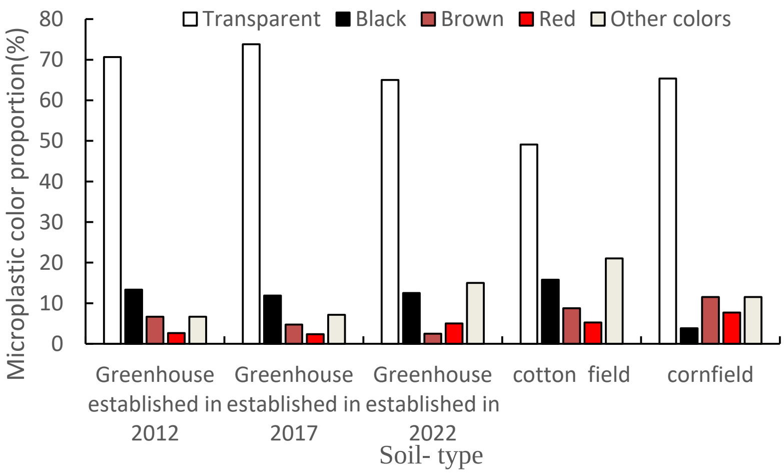


Figure 3 Microplastic Color Characteristics

3.4 Microplastic Particle Size Characteristics

Figure 4 presents data on microplastic concentrations in greenhouse soil for the years 2012, 2017, and 2022. In 2012, microplastics larger than 1000 μm comprised 10.67% of the total, while those ranging from 500 to 1000 μm accounted for 16.00%. Microplastics between 200 and 500 μm made up 24.00%, and those larger than 200 μm constituted 49.33%. By 2017, the proportion of microplastics exceeding 1000 μm increased to 23.81%, whereas the 500 to 1000 μm category decreased to 14.29%. The 200 to 500 μm fraction accounted for 19.05%, and microplastics larger than 200 μm represented 42.86%. In 2022, microplastics greater than 1000 μm further increased to 25.00%, while those between 500 and 1000 μm rose to 22.50%. The 200 to 500 μm category remained stable at 25.00%, but microplastics larger than 200 μm decreased to 27.50%. In cotton field soil, microplastics larger than 1000 μm accounted for 28.07%, while those in the 500 to 1000 μm range constituted 10.53%. The 200 to 500 μm category made up 22.81%, and microplastics larger than 200 μm accounted for 38.60%. In corn fields, microplastics exceeding 1000 μm comprised 3.85%, while those between 500 and 1000 μm accounted for 15.38%. Microplastics in the 200 to 500 μm range represented 11.54%, and those larger than 200 μm constituted 69.23%.

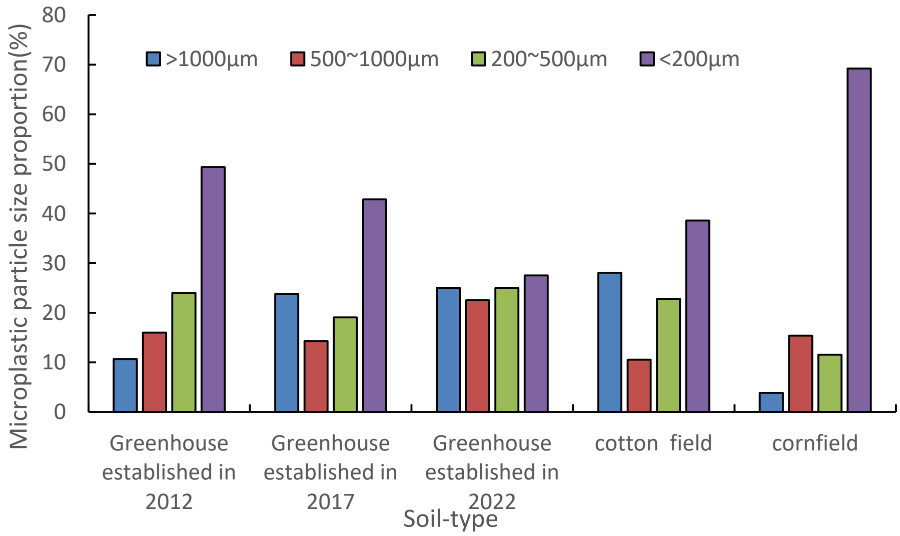


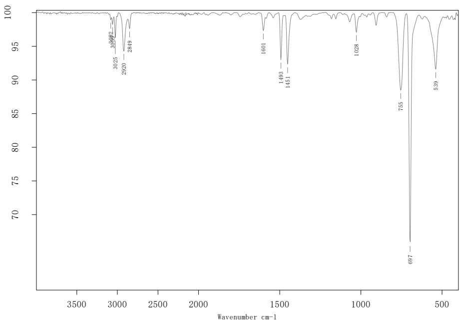
Figure 4 Microplastic Particle Size Characteristics

3.5 Microplastic Component Analysis

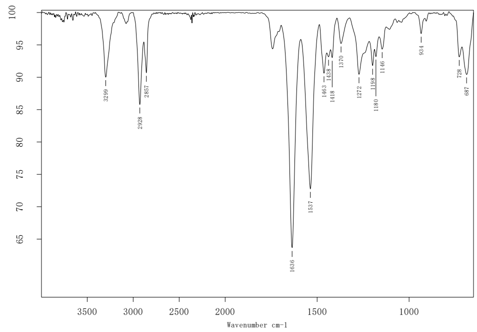
Figure 5 illustrates the various types of microplastic components found in farmland soil, which include polyethylene (PE), polypropylene (PP), polyamide (PA), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET), along with ethylene glycol esters.

Figure 6 illustrates the distribution of microplastics in greenhouse soil across three years: 2012, 2017, and 2022. In 2012, polyethylene (PE) microplastics constituted 30.67%, polypropylene (PP) microplastics accounted for 20.00%, polyamide (PA) microplastics made up 21.33%, polystyrene (PS) microplastics represented 10.67%, and polyvinyl chloride (PVC) microplastics comprised 6.67%. Additionally, polyethylene terephthalate (PET) microplastics accounted for 8.00%, while other types of microplastics contributed 2.67%. Notably, PE was the predominant material. By 2017, the composition shifted, with PE microplastics increasing to 40.48%, PP microplastics rising to 23.81%, PA microplastics decreasing to 19.05%, PS microplastics dropping to 4.76%, and PVC microplastics further declining to 2.38%. PET microplastics accounted for 7.14%, and other types remained at 2.38%, with PE still being the main material. In 2022, the percentages were 37.50% for PE microplastics, 27.50% for PP microplastics, 10.00% for PA microplastics, 7.50% for PS microplastics, and 5.00% for PVC microplastics. PET microplastics accounted for 12.50%, maintaining PE as the primary material. In cotton fields, PE microplastics represented 47.37%, PP microplastics accounted for 14.04%, PA microplastics made up 8.77%, PS microplastics constituted 14.04%, PVC microplastics contributed 3.51%, and PET microplastics also accounted for 3.51%. Other types of microplastics amounted to 3.51%, with

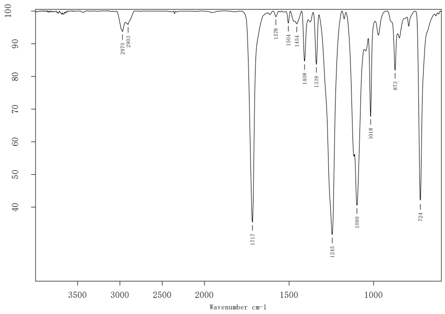
PE being the dominant material. In cornfields, PE microplastics accounted for 38.46%, PP microplastics for 7.69%, PA microplastics for 3.85%, PS microplastics for 11.54%, PVC microplastics for 7.69%, and PET microplastics for 7.69%. The total contribution of plastics was 26.92%, with other types of microplastics representing 3.85%, and PE remaining the primary material.



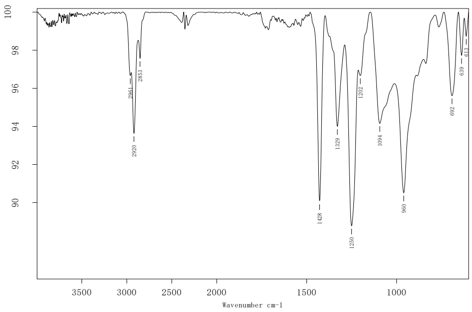
PS



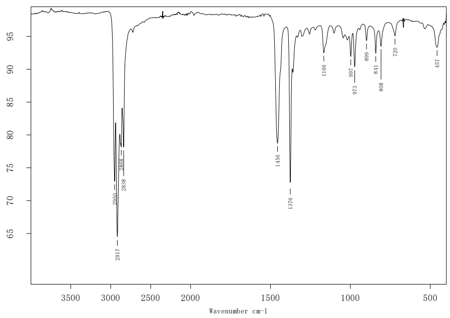
PA



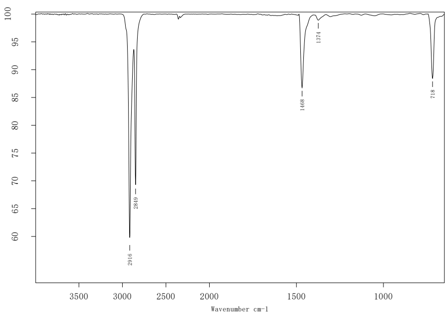
PET



PVC



PP



PE

Figure 5 The composition of microplastics

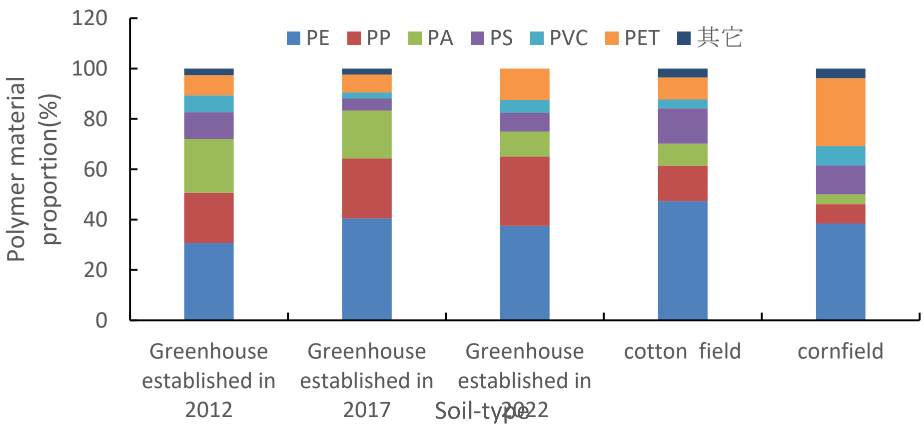


Figure 6 Microplastic Component Analysis

3.6 Risk Assessment of Microplastics in Farm Soil

An analysis and evaluation of the farmland soil in Kashgar City was conducted, with results presented in Table 1. The microplastic pollution load index (PLI) for corn fields was found to be less than 1, while the PLI for cotton fields and greenhouse soils ranged between 1 and 2. This indicates that, in Kashgar City, microplastic pollution in corn fields is classified as mild, whereas the pollution levels in cotton fields and greenhouse soils are considered moderate. Overall, the findings suggest that microplastic pollution in Kashgar City is at a moderate level.

Table 1 Analysis and evaluation results of different soil microplastics

	C_i	CF_i	PL_I	PL_n
Greenhouse established in 2012	1498	2.77	1.66	1.29
Greenhouse established in 2017	824	1.53	1.24	
Greenhouse established in 2022	798	1.48	1.22	
cotton field	1148	2.11	1.45	
cornfield	514	0.95	0.95	

4. Conclusion

Microplastics in farmland soil exhibit a variety of shapes, including film, fiber, granules, and other forms such as blocks, sheets, foams, and rods. Among these, film and fiber are the predominant shapes, collectively accounting for over 60% of the total. The colors of microplastics found in farmland soil range from transparent to black, brown, and red, with transparent microplastics representing the largest proportion, exceeding 50%. Particle sizes of microplastics are categorized into four groups: >1000 μm, 500-1000 μm, 200-500 μm, and <200 μm, with microplastics smaller than 200 μm being the most prevalent. The materials constituting microplastics in farmland soil include polyethylene (PE), polypropylene (PP), polyamide (PA), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET), with PE being the most common material.

The microplastic pollution load index in cornfields of Kashgar City indicates mild pollution, corresponding to a risk level of Category I. In contrast, the microplastic pollution load index for cotton fields and greenhouse soil suggests moderate pollution, with a risk level classified as Category II. Overall, the degree of microplastic pollution in the farmland of Kashgar City is moderate, also categorized as Category II.

Funding: National Natural Science Foundation of China (30900206); Xinjiang University Scientific Research Plan (XJEDU2017M031); Xinjiang Uygur Autonomous Region Natural Foundation of China (2017D01A12).

References

1. Zhang L., Xu H., Yang He., Du Shanghai D., Chiang Mai J. Sci. 2020; 47(5) : 973-983.
2. Ya H., Zhang T., Xing Y., Lv M., Wang X., Jiang B., *Chemosphere*, 2023;335:139082-139082. DOI:10.1016/j.chemosphere.2023.139082.
3. Zhang J., Liu Y., *Science of The Total Environment*. 2018;642:12-20. DOI 10.1016/ j.scitotenv.2018.06.004.
4. Hurley R., Nizzetto L., *Current Opinion in Environmental Science & Health*. 2018;1:6-11.DOI 10.1016 /j.coesh.2017.10.006.
5. Braun M., Amelung, W., *Science of The Total Environment*. 2018;612:422-435. DOI 10.1016/j.scitotenv.2017.08.086.
6. Corradini, F.; Meza, P.; Eguiluz, R.; Casado, F.; Huerta-Lwanga, E.; Science of The Total Environment. 2019;671 (0):411-420. DOI 10.1016/j.scitotenv.2019.03.368.
7. Dris, R, Gasperi, J, Saad, M, Mirande, C,Tassin, B. Marine Pollution Bulletin. 2016;104 (1-2):290-293. DOI 10.1016/j.marpolbul.2016.01.006.
8. Zeb A., Liu W., Ali N; Shi R., Wang J., Li J., Yin C., Liu j., Liu Y., *Journal of Hazardous Materials*. 2024;461:132636-132636. DOI 10.1016/j.jhazmat.2023.132636.
9. Yang, L., Zhang, Y., Kang, S., Wang, Z., Wu, C., *Science of The Total Environment*. 2021;780:146546-146546. DOI 10.1016/j.scitotenv.2021.146546 .
10. Chae,Y.,An Y., *Environmental Pollution*,

.2018;240:38387-395. DOI 10.1016/j.envpol.2018.05.008.
11. Zhou, Y. Wang, J. Zou, M. Jia, Z, Zhou, S, Li, Y. *Science of The Total Environment*, 2020; 748:141368-141368. DOI 10.1016/j.scitotenv.2020.141368.
12. Guo, J., Huang, X., Wang, Y., Li, Y., Li, H., Cai, Q., Mo, C., Wong, M., *Environment International*. 2020;137:105263-105263. doi: 10.1016/j.envint.2019.105263.
13. Zhang Q., Zhang S., Dong W., Wang Z., Mo Z.,. *null*,2024:0-0. DOI 10.5194/egusphere-egu24-2520.
14. Hu C., Wang X., Wang S., Lu B., Guo W., Liu C., Tang X., International Journal of Agricultural and Biological Engineering, 2020 ;13 (1):160-169. DOI10.25165/ijabe.v13i1.5084.
15. Huang Y, Liu Q, Jia W Q, Yan C R, Wang J. *Environmental Pollution*. 2020;260:114096-114096. DOI 10.1016/j.envpol.2020.114096
16. Kim D., Chae Y., An Y., *Environmental Science & Technology*, 2017;51 (21):12852-12858. DOI 10.1021/acs.est.7b03732.
17. Ren X., Tang J., Yu C., He J., *Journal of Agro-Environment Science*. 2018;37 (6):1045-1058. DOI:null.
18. Singh S., Chakma S., Alawa B., Kalyanasundaram M., Diwan V., *Journal of Material Cycles and Waste Management*. 2024,26:708-722., DOI 10.1007/s10163-023-01805-6.
19. Chen M., Coleman B., Gaburici L., Prezgot D., Jakubek Z., Sivarajah S., Vermaire J., Lapen D., Velicogn J., *Science of The Total Environment*. 2024;907:168007. DOI 10.1016/j.scitotenv.2023.168007.
20. Zhang D., Liu H., Hu W., Qin X., Ma Xiao., Yan C., Wang H., Journal of Integrative Agriculture. 2016;15 (11):2639-2646. DOI 10.1016/s2095-3119(15)61240-0.
21. Chen Y., Leng Y., Liu X., Wang J., *Environmental Pollution*. 2020;257:113449-113449. DOI 10.1016/j.envpol.2019.113449
22. Cheng W., Fang T., Wang S., Li S., Zhang J., Zhao Gang., Wang L., Dang Y., *Journal of Agro-Environment Science*, 2020, 39(11): 2561-2568.(in Chinese)
23. Zhang G., Liu Y., *Science of The Total Environment*, 2018; 642:12-20.DOI 10.1016/j.scitotenv.2018.06.004.
24. Lu C., Wu D., Liu P., Hu W.,Sun Y.,Wu Q., Tian K ., Huang B., *Science of The Total Environment*. 2021;794:148694-148694. DOI 10.1016/j.scitotenv.2021.148694.
25. Feng S., Lu H., Liu Y., *Environmental Pollution*.2021;279:116939-116939. DOI 10.1016/j.envpol.2021.116939.
26. Feng S., Lu H., Tian P., Xue Y., Lu J., Meng T., Feng W., *Science of The Total Environment*. 2020;739:140087-140087. DOI 10.1016/j.scitotenv.2020.140087.
27. Feng S., Lu H., Yao T., *Journal of Environmental Chemical Engineering*. 2023;11 (3):109657-109657.DOI 10.1016/j.jece.2023.109657.
28. Zhang W. *Zhengzhou: Henan University*, 2020.DOI 10.27114/d.cnki.ghnau.2020.001197.
29. Guo S., Zhang J., Liu J., Guo Ning., Zhang L., Wang S., Wang X., Zhao M., Zhang B., Chen Y., *Science of The Total Environment*. 2023 ;895:165005-165005.DOI 10.1016/j.scitotenv.2023.165005.
30. Yang X., Zhang Z., Guo X., *Science of The Total Environment*. 2023;902:166189-166189. DOI 10.1016/j.scitotenv.2023.166189.
31. Ding L., Zhang S., Wang X., Yang X., Zhang C., Qi Y., Guo X., *Science of The Total Environment*. 2020;720:137525-137525. DOI 10.1016/j.scitotenv.2020.137525.
32. Li Z., Xu B., Zhang R., Wang F., Li L., Wang K., Zhang R., Jing X., Chen P., *Chemosphere*. 2023;338:139389-139389. DOI 10.1016/j.chemosphere.2023.139389.
33. Li W., Wang S., Wufuer R., Duo J., Pan X., *International Journal of Environmental Research and Public Health*. 2022;19 (15): 8890-8890. DOI 10.3390/ijerph19158890.
34. Lv W., Zhou W., Lu S., Huang W., Yuan Q., Tian M., Lv W., He D., *Science of The Total Environment*. 2019;652:1209-1218.DOI 10.1016/j.scitotenv.2018.10.321.
35. Dong M., Luo Z., Xin X., Zhang Q., Sun Y., *Research of Environmental Sciences*, 2020,33 (06):1522-1529.DOI 10.13198/j.issn.1001-6929.2019.10.05.(in Chinese)
36. Everaert G., Van Cauwenberghe L.,De Rijcke M., Koelmans A.,Mees J.,Vandegehuchte M.,JanssenC.,*EnvironmentalPollution*,2018;242:1930-1938. DOI 1061/j.envpol.2018.07.069.
37. Hong W., Lee K., Tang K., Yap P., Science of The Total Environment. 2020;719:137512-

137512. DOI 10.1016/j.scitotenv.2020.137512.

38. Berg P., Huerta E., Corradini F., Geissen V., Environmental Pollution. 2020;261:114198-114198. DOI 10.1016/j.envpol.2020.114198.
39. Can Hu., Bing Lu., Guo W., Tang X., Wang X., Xue Y., Wang L.,He X., *International Journal of Agricultural and Biological Engineering.* 2021;14 (2):196-204. DOI 10.25165/ijabe.v14i2.6165.
40. Wang J., LI B., Hou Y.,Journal of Agro-Environment Science, 2023, 42(5):951-965.(in Chinese)
41. Sun X., Gou Y., Yan H., Tang Q., Yang Z L,.*Journal of Agro-Enviriinment scientce,* 2024,43(3):571-580. DOI 10.19980/j.CN23-1593/G4.2024.06.043. (in Chinese)