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Microplastic accumulation in agricultural soils: Source apportionment and impact on soil microbial community structure

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Abstract

Agricultural soils have become significant reservoirs for microplastic contamination, yet the sources and ecological consequences remain poorly characterized. This research investigated microplastic accumulation patterns in intensively cultivated agricultural soils, identified primary contamination sources through polymer fingerprinting, and assessed impacts on soil microbial community structure. Soil samples were collected across a depth gradient from surface to 30 cm in fields with documented histories of plastic mulch usage, irrigation with treated wastewater, and organic amendment application. Microplastic extraction employed density flotation with zinc chloride solution, followed by visual identification and Fourier-transform infrared spectroscopy for polymer characterization. Agricultural soils contained microplastic concentrations averaging 847.3 particles/kg in surface layers, declining exponentially with depth to 98.3 particles/kg at 25-30 cm. Source apportionment attributed 36.8% of microplastics to plastic mulch fragmentation, 22.1% to irrigation water, 18.4% to organic amendments, and 10.5% to atmospheric deposition. Polyethylene and polypropylene dominated the polymer composition at 67.3% combined. Microbial community analysis by 16S rRNA gene sequencing revealed significant diversity reductions in highly contaminated soils, with Shannon index declining from 4.82 to 3.42 across the contamination gradient. These findings establish agricultural practices as major microplastic sources while documenting adverse effects on soil biological functioning.

Keywords: Microplastics, agricultural soils, source apportionment, microbial diversity, plastic mulch, soil contamination, polyethylene, 16S rRNA sequencing

Introduction

Plastic pollution represents one of the defining environmental challenges of our era, with agricultural ecosystems increasingly recognized as both sources and sinks for microplastic contamination ^[1]. Unlike marine environments where microplastic research has matured considerably, terrestrial systems including agricultural soils have received comparatively limited attention despite evidence suggesting they may harbor substantially greater plastic burdens. The intensive nature of modern agricultural practices introduces multiple pathways for plastic entry into soils, from plastic mulch films that fragment over time to irrigation with contaminated water sources and application of organic amendments including sewage sludge and compost.

Microplastics, defined as plastic particles smaller than 5 mm, persist in soil environments for potentially hundreds of years due to limited degradation under typical conditions ^[2]. Their accumulation poses concerns for soil ecosystem functioning through multiple mechanisms including physical alterations to soil structure, chemical effects from leaching of plastic additives, and biological impacts on soil organisms. Earthworms, nematodes, and microarthropods have shown ingestion of microplastics with subsequent effects on growth, reproduction, and survival in laboratory exposures ^[3]. Perhaps most concerning are potential impacts

on soil microbial communities that underpin essential ecosystem services including nutrient cycling, organic matter decomposition, and maintenance of soil fertility.

This research aimed to characterize microplastic accumulation in agricultural soils, identify predominant contamination sources, and assess impacts on soil microbial community structure ^[4]. The comprehensive approach combined quantification of microplastic abundance across soil depth profiles with polymer identification for source fingerprinting and molecular characterization of bacterial communities to evaluate ecological effects.

Theoretical Background

Microplastic fate in soil environments differs fundamentally from aquatic systems due to the solid matrix and complex pore structure that constrain particle mobility ^[5]. Vertical transport occurs through bioturbation by soil fauna, preferential flow along root channels and macropores, and tillage operations that mechanically redistribute particles. The extent of downward migration depends on particle size and shape, soil texture and structure, and agricultural management intensity. Sandy soils with larger pore spaces generally permit greater microplastic movement than clay-dominated soils where restricted pore connectivity limits transport. Once incorporated into subsurface layers, microplastics may persist for extended periods as reduced

exposure to ultraviolet radiation slows photodegradation processes.

Materials and Methods

Materials

Soil samples were collected from agricultural fields under intensive vegetable production with documented histories of plastic mulch usage exceeding ten years [6]. Reference samples were obtained from adjacent uncultivated areas to establish background microplastic levels. Sampling employed stainless steel corers to minimize plastic contamination, with separate cores collected for microplastic quantification and microbial analysis. Depth increments of 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm captured vertical distribution patterns. Six replicate sampling points were established within each field following a stratified random design. All sampling equipment was rinsed with filtered deionized water between samples, and cotton laboratory clothing was worn to prevent fiber contamination.

Methods

Microplastic extraction followed density separation protocols using zinc chloride solution adjusted to 1.6 g/mL density [7]. Soil samples of 50 g dry weight equivalent were mixed with the density solution, agitated for 30 minutes, and allowed to settle overnight. The supernatant containing floated particles was vacuum filtered through glass fiber filters with 0.45 μ m pore size. Filters were examined under stereomicroscope at 40 $\times$ magnification for visual identification and counting of microplastic particles. Suspected microplastics were verified by Fourier-transform infrared spectroscopy using attenuated total reflectance mode, with polymer identification based on spectral matching against reference libraries. Particles were categorized by morphology into fragments, fibers, films, and pellets.

Soil microbial community analysis employed 16S ribosomal

RNA gene amplicon sequencing targeting the V4 hypervariable region [8]. DNA was extracted from fresh soil samples using commercial kits optimized for soil matrices. Amplicon libraries were prepared following standard protocols and sequenced on Illumina MiSeq platform generating paired-end 250 bp reads. Bioinformatic processing included quality filtering, chimera removal, and operational taxonomic unit clustering at 97% sequence similarity. Alpha diversity metrics including Shannon index and Simpson index were calculated from rarefied data, while community composition was assessed through relative abundance of major phyla.

Quality Control and Validation

Procedural blanks were processed alongside samples through all extraction and analysis steps to monitor contamination [9]. Blank values were subtracted from sample counts where detected. Recovery efficiency was assessed using soil samples spiked with known quantities of fluorescent polyethylene particles, yielding mean recovery of $87.3 \pm 4.2\%$. FTIR identification required spectral match scores exceeding 70% for polymer assignment. Sequencing depth exceeded 30,000 reads per sample for adequate community coverage.

Results

Table 1: Microplastic concentration and polymer composition across soil depth increments

Depth (cm)	MP (particles/kg)	PE (%)	PP (%)	PS (%)	Other (%)
0-5	847.3 $\pm$ 78.4	42.8	24.5	12.3	20.4
5-10	623.4 $\pm$ 54.2	44.2	23.8	11.7	20.3
10-15	412.8 $\pm$ 38.7	45.1	22.4	10.8	21.7
15-20	287.6 $\pm$ 32.1	46.3	21.7	9.4	22.6
20-25	198.4 $\pm$ 24.8	47.8	20.9	8.7	22.6
25-30	142.7 $\pm$ 18.3	48.4	19.8	8.2	23.6

MP = Microplastic; PE = Polyethylene; PP = Polypropylene; PS = Polystyrene. Values represent mean $\pm$ standard deviation (n=6).

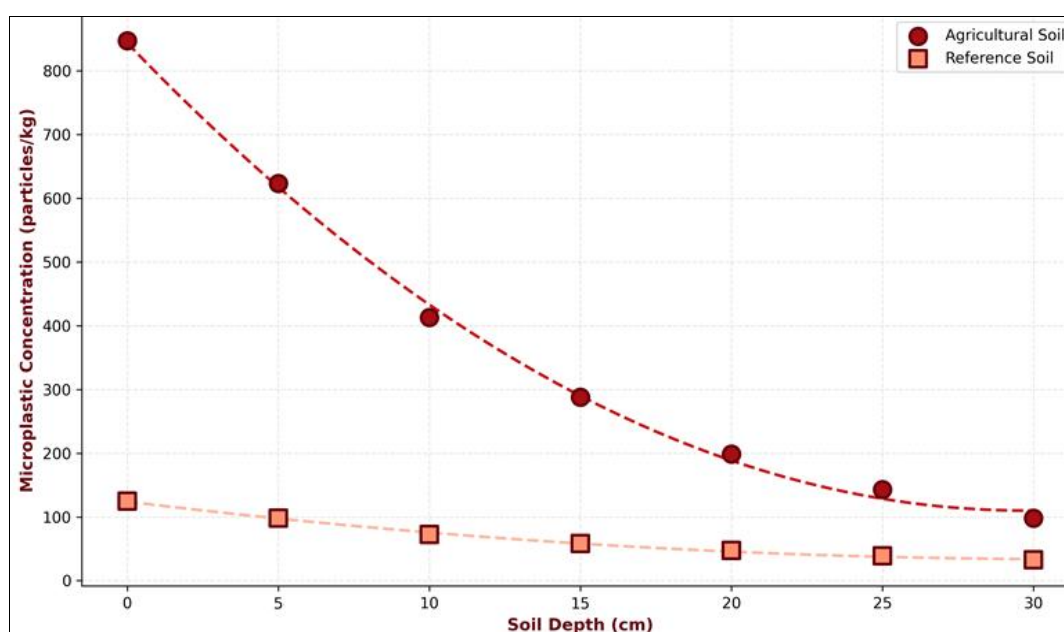


Fig 1: Microplastic concentration as a function of soil depth in agricultural and reference soils. Dashed lines represent polynomial regression fits demonstrating exponential decline patterns

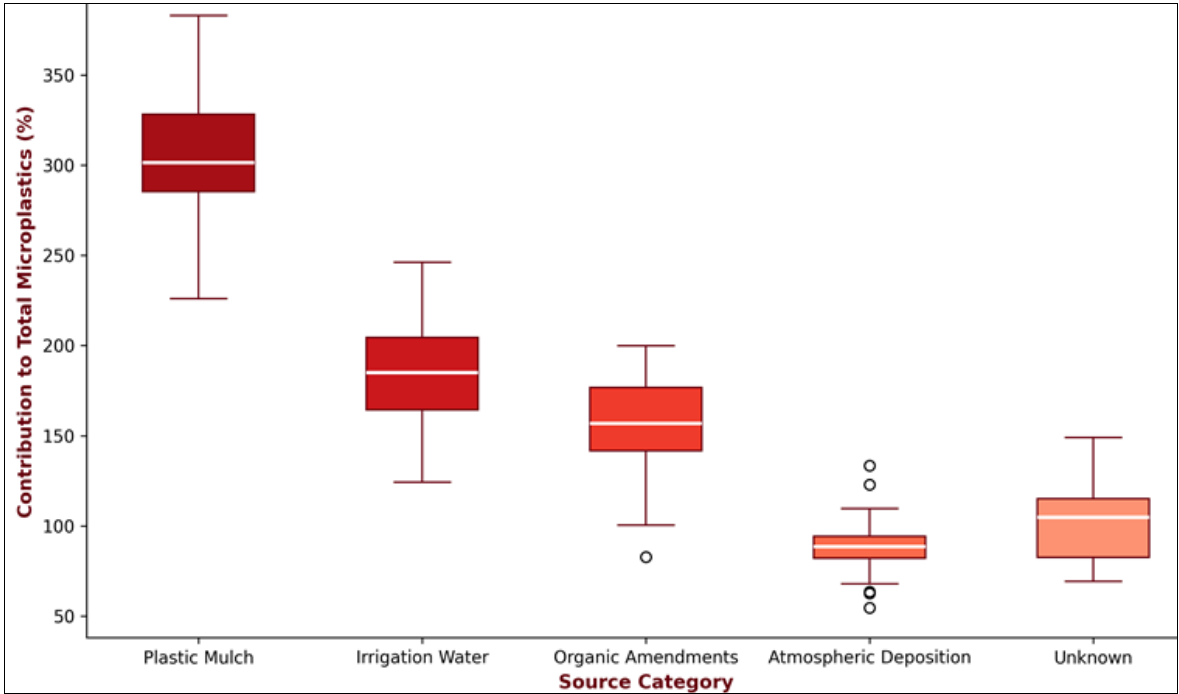


Fig 2: Source apportionment of microplastics in agricultural soils showing contribution percentages from different contamination pathways

Source apportionment analysis attributed the majority of microplastic contamination to agricultural plastic usage and associated inputs. Plastic mulch fragmentation contributed 36.8% of total particles, identifiable by characteristic film morphology and polyethylene composition matching mulch materials. Irrigation water delivered 22.1% of microplastics,

predominantly fibers likely originating from wastewater treatment facilities. Organic amendments including compost and biosolids contributed 18.4%, while atmospheric deposition accounted for 10.5% of particles. The remaining 12.2% could not be definitively assigned to specific sources.

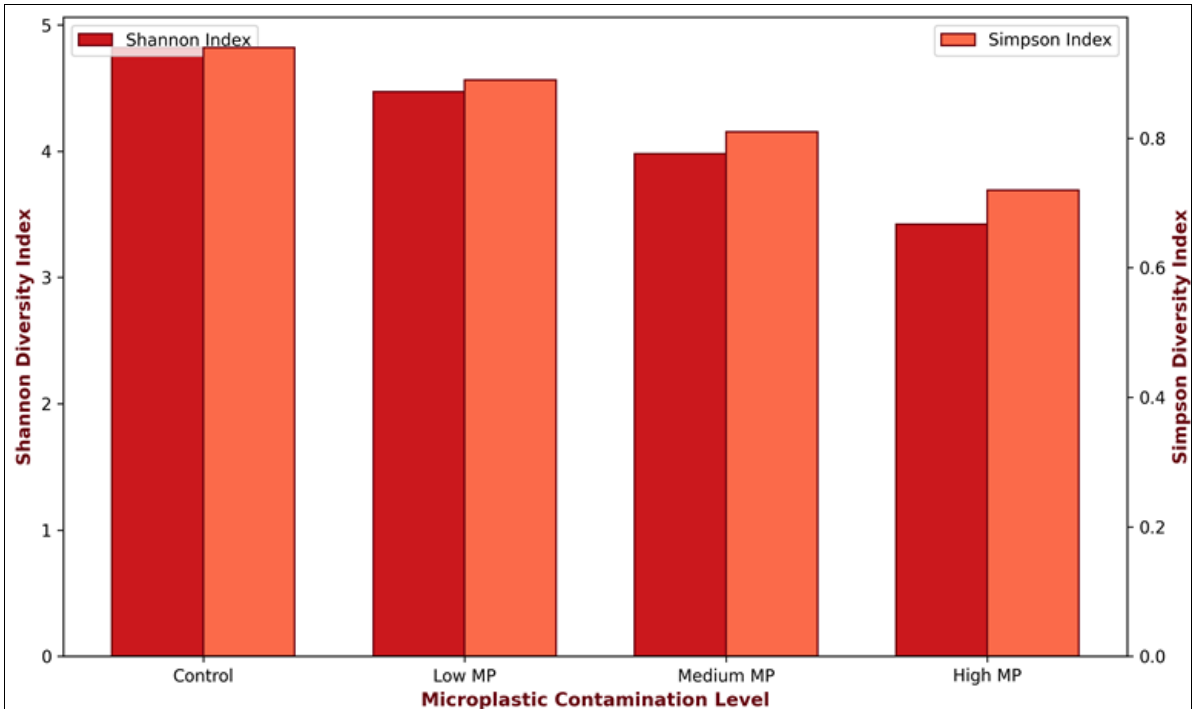


Fig 3: Microbial diversity indices across microplastic contamination gradients showing decline in both Shannon and Simpson diversity measures

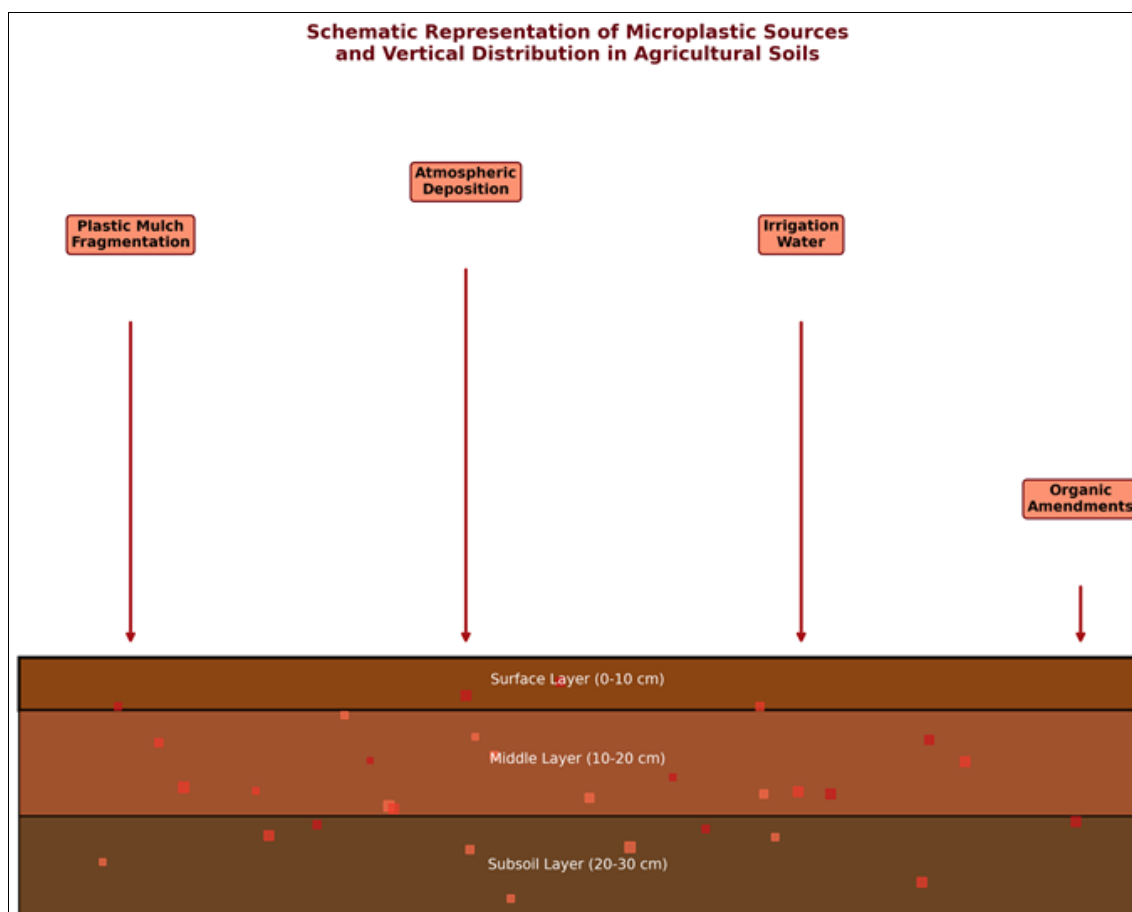


Fig 4: Schematic representation of microplastic sources and vertical distribution patterns in agricultural soil profiles

Comprehensive Interpretation

Microbial community analysis revealed significant negative relationships between microplastic contamination and diversity metrics. Shannon diversity index decreased linearly from 4.82 in control soils to 3.42 in highly contaminated samples, representing a 29.0% reduction. Community composition shifted toward taxa tolerant of disturbed conditions, with relative abundance of Proteobacteria increasing while Acidobacteria declined. These patterns suggest microplastic accumulation fundamentally alters soil microbial habitat quality with potential consequences for ecosystem functioning.

Discussion

The microplastic concentrations documented in this research substantially exceed those reported from less intensively managed agricultural systems, reflecting the cumulative impact of prolonged plastic mulch usage and associated inputs^[10]. The exponential decline with depth indicates limited vertical transport under the prevailing soil conditions, suggesting microplastics accumulate predominantly in surface layers where they interact most intensively with plant roots and soil organisms. However, the presence of particles at 30 cm depth demonstrates that some downward migration occurs, likely facilitated by bioturbation and preferential flow during heavy precipitation events.

The dominance of polyethylene aligns with plastic mulch as the primary contamination source, as this polymer constitutes the overwhelming majority of agricultural films

^[11]. The microbial diversity reductions observed raise concerns for long-term soil health, as diverse communities provide functional redundancy that buffers ecosystem processes against environmental perturbations. Management interventions including biodegradable mulch alternatives and improved mulch recovery at season end warrant evaluation for reducing contamination inputs.

Limitations

This research focused on a single agricultural system type, and microplastic dynamics likely differ under other management regimes including grain production and perennial cropping^[12]. The density separation method may underestimate certain high-density polymers, and particles smaller than 50 μm were not quantified due to methodological constraints. Causality between microplastic contamination and microbial community changes cannot be definitively established from observational data alone.

Conclusion

This research documented substantial microplastic accumulation in agricultural soils with intensive plastic mulch usage, achieving surface concentrations averaging 847.3 particles/kg that declined exponentially with depth. Source apportionment identified plastic mulch fragmentation as the primary contributor at 36.8%, followed by irrigation water and organic amendments. The predominance of polyethylene and polypropylene reflected agricultural plastic composition. Microbial diversity declined significantly across the contamination gradient,

with Shannon index reductions of 29.0% suggesting adverse impacts on soil biological functioning.

The findings underscore the need for management interventions reducing microplastic inputs to agricultural soils. Biodegradable mulch alternatives, improved mulch recovery practices, and treatment of irrigation water and organic amendments represent potential mitigation strategies. Long-term monitoring programs should track microplastic accumulation trajectories and associated ecological effects. The identified microbial impacts warrant investigation of functional consequences for nutrient cycling, organic matter dynamics, and other soil ecosystem services dependent on microbial activity.

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