



Microplastic Transport Through Agricultural Soil Profiles Into Shallow Groundwater

Hiroshi Joseph^{1*}, Dana Olsen², Nikola Raghavan³

¹Department of Civil, Skagerrak Research Institute of Civil, Switzerland

²Department of Civil, Anatolian School of Civil, Malaysia

³Department of Civil, Orinoco Institute of Civil, Ireland

Article Info

Volume 1, Issue 1, 2026

doi: [10.62715/ijsws.2026.v1.i1.pp7-13](https://doi.org/10.62715/ijsws.2026.v1.i1.pp7-13)

Received: 22 March 2026

Accepted: 24 May 2026

Published: 21 July 2026

Abstract

Agricultural land receives plastic particles from sewage sludge, compost, mulch films, irrigation water and the atmosphere, and concern has grown that some of this material may travel downward and reach the shallow aquifers on which rural water supplies depend. This narrative review brings together what is known about that pathway. It describes the inputs to cultivated soil, then considers the processes that move particles through the plough layer and below it: mixing by tillage, carriage by earthworms and other fauna, and transport in percolating water. Classical colloid filtration theory predicts that most particles larger than a few micrometres will be strained out within a short distance in a uniform porous medium. Structured field soils are not uniform, however, and preferential flow through macropores, cracks and burrows can bypass the filtering matrix. The few published surveys of groundwater report plastic particles mainly in karst and other rapidly recharged systems, and their interpretation is limited by sampling contamination and inconsistent methods. The review concludes that the fine fraction, including nanoplastics, is the most mobile and the least measured, and that field studies linking surface loading, soil structure and groundwater quality at the same site are the principal gap.

Keywords: Microplastics, Agricultural soil, Vertical transport, Preferential flow, Colloid filtration, Shallow groundwater

© 2026 Hiroshi Joseph et al. This is an open access article under the CC BY license (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

1. Introduction

The word microplastics entered the scientific vocabulary through marine science, when Thompson *et al.* (2004) drew attention to microscopic plastic fragments and fibres in sediments and plankton samples. For some years the subject stayed at sea. Rillig (2012) was among the first to ask whether soils, which receive plastic from many of the same sources, might be affected as well, and later estimates suggested that the quantity added to farmland each year through sewage sludge alone could rival or exceed the stock floating on the surface of the oceans (Nizzetto *et al.*, 2016).

Microplastics are most often defined as plastic particles smaller than 5 mm, with nanoplastics forming

* Corresponding author: Hiroshi Joseph, Department of Civil, Skagerrak Research Institute of Civil, Switzerland. E-mail: hiroshi.joseph@skagerrak.edu

© 2026 Hiroshi Joseph et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

the fraction below one micrometre, although the boundaries and the vocabulary of shapes and polymer types are still being harmonised (Hartmann *et al.*, 2019). Research on their behaviour in terrestrial systems has expanded quickly, and several reviews now treat soil as a major reservoir (de Souza Machado *et al.*, 2018; Hurley and Nizzetto, 2018). Most of that work concerns the topsoil and the organisms that live in it.

The question taken up here is what happens below. Shallow groundwater beneath farmland supplies wells, feeds streams and is already known to be vulnerable to nitrate and pesticides that originate at the surface. Whether plastic particles follow the same route depends on processes that soil physics and colloid science have studied for decades in other contexts. This review connects that older knowledge with the newer literature on microplastics in soil and groundwater.

2. Approach of the Review

The article is a narrative review of the published literature. It was not designed as a systematic search, and it makes no claim to cover every study. Sources were selected to represent four bodies of work: studies of plastic inputs to agricultural soil, experiments on the movement of plastic particles in soil, the established theory of colloid transport in porous media, and surveys of plastic particles in groundwater. Where the microplastic literature is thin, the review relies on well-tested principles from the study of other particles and says so.

3. Sources of Plastic in Cultivated Soil

Sewage sludge is the best documented input. Treatment works retain most of the particles in wastewater, which concentrates them in the solids that are then spread on land. Zubris and Richards (2005) showed that synthetic fibres could be used as a marker of sludge application because they remained detectable in soil long after spreading had ceased, and Corradini *et al.* (2019) found that the microplastic content of field soils rose with the number of sludge applications they had received. Composts and digestates made from municipal organic waste carry fragments of packaging that survive sorting.

Plastic mulch film is the second large source. Thin polyethylene films are difficult to recover completely after harvest, and the residues are broken up by tillage and weathering into progressively smaller pieces (Steinmetz *et al.*, 2016). Irrigation with untreated or partly treated wastewater, littering, wear of tyres on farm tracks and deposition from the air add smaller amounts. The result is a surface layer loaded with particles of many sizes, shapes and densities, from fibres millimetres long to fragments too small to see.

4. Movement Within the Soil Profile

Three kinds of process carry particles downward: mechanical mixing, biological transport and movement with water. They operate over different depths and select for different particle sizes.

4.1. Tillage and bioturbation

Ploughing distributes surface-applied material through the tilled layer within a season or two, and it places some particles at the plough sole, where the soil below is denser and less disturbed. Soil animals then extend the reach. Huerta Lwanga *et al.* (2016) exposed the deep-burrowing earthworm *Lumbricus terrestris* to polyethylene particles mixed with surface litter, and a companion study found the particles incorporated into burrow walls (Huerta Lwanga *et al.*, 2017). Rillig *et al.* (2017) demonstrated the same species carrying polyethylene beads down the profile, with the smallest size class travelling furthest. Fauna matter doubly, because the burrows they leave are also the channels through which water later moves fastest.

4.2. Transport in percolating water

Particles suspended in water moving through a granular medium are removed by two mechanisms. Straining occurs when a particle is too large to pass a pore throat, and its importance grows with the ratio of particle to grain diameter (Bradford *et al.*, 2002). Attachment occurs when a particle collides with a

grain surface and adheres. Colloid filtration theory, developed for water treatment by Yao *et al.* (1971) and refined by Tufenkji and Elimelech (2004), predicts the collision rate from diffusion, interception and sedimentation, and shows a minimum in removal for particles of roughly a micrometre, which are too large to diffuse quickly and too small to settle or be intercepted efficiently.

Whether a collision leads to attachment depends on surface chemistry. Most plastics and most soil minerals carry negative charge at ordinary soil pH, so attachment is unfavourable in dilute water and becomes easier as ionic strength rises or divalent cations such as calcium are present. Weathering, biofilm growth and coatings of organic matter change the surface properties of plastic particles and make their behaviour difficult to predict from the polymer alone (Alimi *et al.*, 2018). Shape and density add further complications. Fibres align with the flow and can thread through pores much narrower than their length, whereas films and irregular fragments lodge more readily. Polyethylene and polypropylene are less dense than water and polyester and polyvinyl chloride are denser, so that settling assists the removal of some polymers and not others.

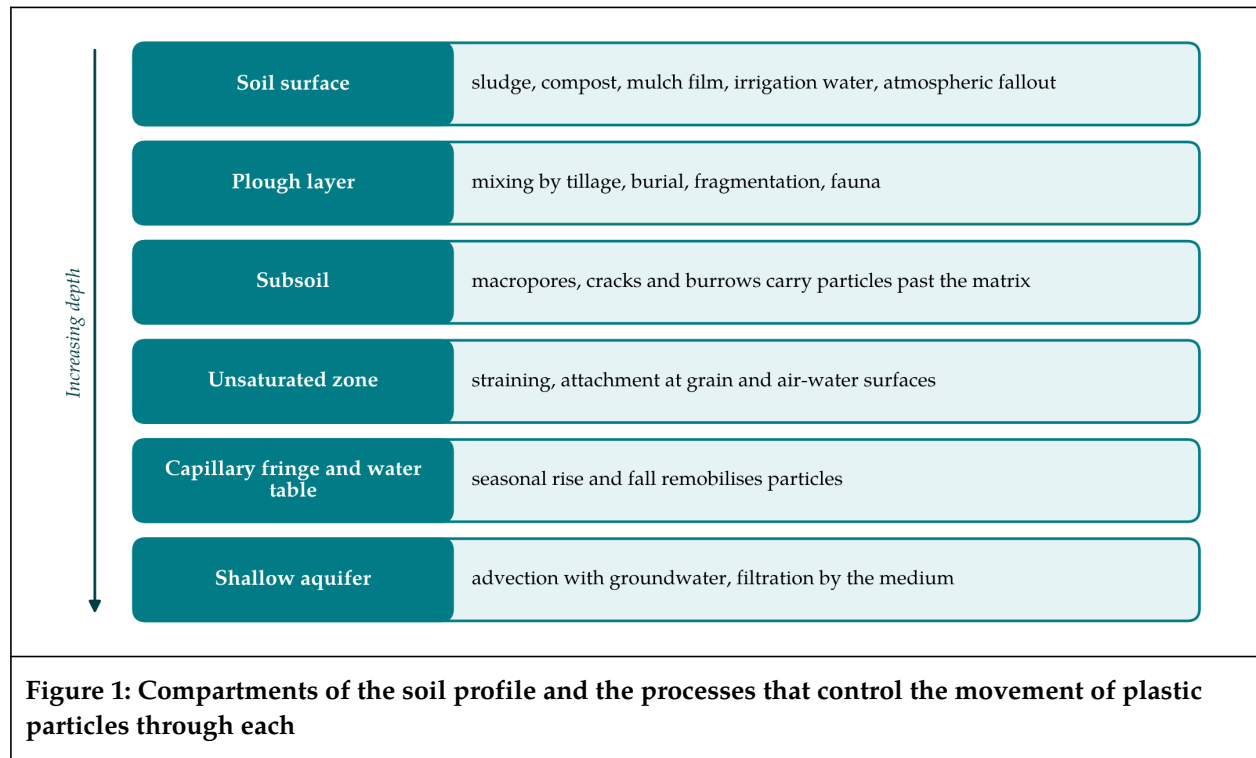
Most of this theory was developed for saturated media, and the root zone is seldom saturated. In unsaturated soil the interface between air and water offers a further site of retention, and it moves as the soil wets and dries. Thin water films also confine particles to the smaller pores, where straining is more likely. Drying can therefore hold particles in place for long periods, and an advancing wetting front can release many of them at once. Column experiments in sand have indeed found that repeated wet and dry cycles carry microplastics deeper, and that small particles travel further than large ones (O'Connor *et al.*, 2019). Table 1 summarises the main processes, the particles they act on and their likely consequence for transport to depth.

Table 1: Processes governing the vertical movement of plastic particles in agricultural soil			
Process	Particles most affected	Effect on downward transport	Key sources
Tillage	All sizes	Mixes particles through the plough layer only	Steinmetz <i>et al.</i> , 2016
Bioturbation	Particles small enough to be ingested or carried	Moves particles into burrows below tilled depth	Rillig <i>et al.</i> , 2017
Straining	Large relative to pore throats	Stops particles near the point of entry	Bradford <i>et al.</i> , 2002
Attachment	Colloidal sizes	Retards transport; depends on water chemistry	Tufenkji and Elimelech, 2004
Wet-dry cycling	Small particles	Remobilises retained particles	O'Connor <i>et al.</i> , 2019
Preferential flow	All sizes that fit the channel	Bypasses the filtering matrix	Jarvis, 2007

4.3. Preferential flow

Filtration theory describes a uniform bed of grains. Field soils are structured. Earthworm burrows, old root channels, shrinkage cracks in clay and the gaps between aggregates form continuous large pores that conduct water rapidly when rain or irrigation exceeds the infiltration capacity of the matrix (Beven and Germann, 1982). Water in these channels has little contact with the surrounding soil, and solutes and particles that would otherwise be retained can be carried to drains or to the water table within hours (Jarvis, 2007). The mobilisation of natural colloids by such flow, and their capacity to carry strongly sorbed contaminants with them, has been recognised for a long time (McCarthy and Zachara, 1989). Nothing in the physics distinguishes a plastic fragment from a clay particle of the same size and density, so preferential flow should be expected to be the dominant route by which microplastics reach depth in structured soils.

Figure 1 sets the processes in the order a particle meets them on its way down. The upper layers are dominated by mechanical and biological mixing, the middle layers by the contest between bypass flow and retention in the matrix, and the lowest by the fluctuation of the water table, which periodically floods soil that has accumulated particles and may release them.



5. Evidence From Groundwater

Direct measurements in aquifers are scarce. [Panno et al. \(2019\)](#) reported microplastic fibres in springs and wells of karst aquifers together with pharmaceuticals and other markers of wastewater, a setting in which conduits connect the surface to groundwater with almost no filtration. [Mintenig et al. \(2019\)](#) examined raw groundwater and the drinking water produced from it and found very low numbers of small fragments, whose polymer types suggested that abrasion of plastic components in the wells and treatment plant was at least as likely a source as the aquifer. [Re \(2019\)](#) reviewed the hydrogeological reasoning and argued that fibres deserve particular attention because their small diameter allows passage through pores that would retain a fragment of the same length.

These findings fit the theory. Rapidly recharged systems, such as karst, fractured rock and coarse gravels, are those in which particles have been found, and granular aquifers appear to be well protected against all but the finest fraction. The inference must be held loosely, because the number of studies is small and the data are of uneven quality. A critical assessment of studies on microplastics in fresh and drinking water concluded that few met basic criteria for sampling, blank correction and polymer identification ([Koelmans et al., 2019](#)).

6. Limits of Current Methods

Measuring microplastics in soil is harder than in water. Particles must be separated from a matrix of mineral grains and organic matter, usually by flotation in a dense salt solution followed by chemical digestion of organic residues, and then identified by infrared or Raman microscopy or by thermal methods such as pyrolysis coupled to gas chromatography and mass spectrometry ([Bläsing and Amelung, 2018](#)). Each step loses some particles, and the losses are greatest for the smallest sizes, which are also the most mobile. Spectroscopic identification becomes impractical well above the nanometre range, so the fraction most likely to reach groundwater is the fraction about which least is known.

Contamination is the second difficulty. Groundwater is sampled through plastic well casings, pumps and tubing, and laboratory air carries textile fibres. Without field and procedural blanks a low count cannot be distinguished from background. Studies also report results in different units, counts per volume or mass per mass, over different size ranges, which prevents comparison between sites and makes mass balances between soil and aquifer impossible to close.

7. Gaps and Future Work

The largest gap is the absence of studies that follow particles from surface to water table at a single site. What is needed is a field with a known history of sludge or mulch use, sampled by depth through the unsaturated zone, with the soil structure characterised and the underlying groundwater monitored through wet and dry seasons using plastic-free equipment. Tile-drained fields offer a convenient intermediate step, since drain outflow integrates preferential flow over a known area and can be sampled during storms.

Laboratory work should move from repacked sand to undisturbed soil monoliths, and from pristine spheres to weathered fragments and fibres of the polymers found in fields. Transport models developed for colloids and pathogens can be adapted, but they require attachment and straining parameters for realistic particles. Finally, the role of plastic particles as carriers of sorbed pesticides or metals, by analogy with natural colloids, has been proposed more often than it has been tested in soil.

8. Conclusion

Agricultural soils receive plastic particles in quantity, and several mechanisms move them below the surface. Tillage and soil animals redistribute them within the upper profile. Percolating water can carry them further, but the soil matrix is an effective filter for all except the smallest particles unless structure allows water to bypass it. Shallow groundwater beneath structured or fractured materials is therefore the most exposed, and the limited survey evidence agrees. Present methods cannot quantify the fine fraction that theory identifies as most mobile. Until measurements at field sites connect loading, soil structure and groundwater quality, statements about the scale of the pathway should be made with caution in either direction.

Conflict of interest

To be declared by the author(s) before publication.

Funding

To be declared by the author(s) before publication.

References

- Alimi, O.S., Farner Budarz, J., Hernandez, L.M. and Tufenkji, N. (2018). [Microplastics and nanoplastics in aquatic environments: Aggregation, deposition, and enhanced contaminant transport](#). *Environmental Science & Technology*, 52(4): 1704-1724. <https://doi.org/10.1021/acs.est.7b05559>
- Beven, K. and Germann, P. (1982). [Macropores and water flow in soils](#). *Water Resources Research*, 18(5): 1311-1325. <https://doi.org/10.1029/WR018i005p01311>
- Bläsing, M. and Amelung, W. (2018). [Plastics in soil: Analytical methods and possible sources](#). *Science of the Total Environment*, 612: 422-435. <https://doi.org/10.1016/j.scitotenv.2017.08.086>
- Bradford, S.A., Yates, S.R., Bettahar, M. and Simunek, J. (2002). [Physical factors affecting the transport and fate of colloids in saturated porous media](#). *Water Resources Research*, 38(12): 1327. <https://doi.org/10.1029/2002WR001340>
- Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E. and Geissen, V. (2019). [Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal](#). *Science of the Total Environment*, 671: 411-420. <https://doi.org/10.1016/j.scitotenv.2019.03.368>

- de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S. and Rillig, M.C. (2018). [Microplastics as an emerging threat to terrestrial ecosystems](#). *Global Change Biology*, 24(4): 1405-1416. <https://doi.org/10.1111/gcb.14020>
- Hartmann, N.B., Hüffer, T., Thompson, R.C., Hassellöv, M., Verschoor, A., Daugaard, A.E., Rist, S., Karlsson, T., Brennholt, N., Cole, M., Herrling, M.P., Hess, M.C., Ivleva, N.P., Lusher, A.L. and Wagner, M. (2019). [Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris](#). *Environmental Science & Technology*, 53(3): 1039-1047. <https://doi.org/10.1021/acs.est.8b05297>
- Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., van der Ploeg, M., Besseling, E., Koelmans, A.A. and Geissen, V. (2016). [Microplastics in the terrestrial ecosystem: Implications for *Lumbricus terrestris* \(Oligochaeta, Lumbricidae\)](#). *Environmental Science & Technology*, 50(5): 2685-2691. <https://doi.org/10.1021/acs.est.5b05478>
- Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., van der Ploeg, M., Besseling, E., Koelmans, A.A. and Geissen, V. (2017). [Incorporation of microplastics from litter into burrows of *Lumbricus terrestris*](#). *Environmental Pollution*, 220: 523-531. <https://doi.org/10.1016/j.envpol.2016.09.096>
- Hurley, R.R. and Nizzetto, L. (2018). [Fate and occurrence of micro\(nano\)plastics in soils: Knowledge gaps and possible risks](#). *Current Opinion in Environmental Science & Health*, 1: 6-11. <https://doi.org/10.1016/j.coesh.2017.10.006>
- Jarvis, N.J. (2007). [A review of non-equilibrium water flow and solute transport in soil macropores: principles, controlling factors and consequences for water quality](#). *European Journal of Soil Science*, 58(3): 523-546. <https://doi.org/10.1111/j.1365-2389.2007.00915.x>
- Koelmans, A.A., Mohamed Nor, N.H., Hermesen, E., Kooi, M., Mintenig, S.M. and De France, J. (2019). [Microplastics in freshwaters and drinking water: Critical review and assessment of data quality](#). *Water Research*, 155: 410-422. <https://doi.org/10.1016/j.watres.2019.02.054>
- McCarthy, J.F. and Zachara, J.M. (1989). [Subsurface transport of contaminants](#). *Environmental Science & Technology*, 23(5): 496-502. <https://doi.org/10.1021/es00063a001>
- Mintenig, S.M., Löder, M.G.J., Primpke, S. and Gerdts, G. (2019). [Low numbers of microplastics detected in drinking water from ground water sources](#). *Science of the Total Environment*, 648: 631-635. <https://doi.org/10.1016/j.scitotenv.2018.08.178>
- Nizzetto, L., Futter, M. and Langaas, S. (2016). [Are agricultural soils dumps for microplastics of urban origin?](#) *Environmental Science & Technology*, 50(20): 10777-10779. <https://doi.org/10.1021/acs.est.6b04140>
- O'Connor, D., Pan, S., Shen, Z., Song, Y., Jin, Y., Wu, W.-M. and Hou, D. (2019). [Microplastics undergo accelerated vertical migration in sand soil due to small size and wet-dry cycles](#). *Environmental Pollution*, 249: 527-534. <https://doi.org/10.1016/j.envpol.2019.03.092>
- Panno, S.V., Kelly, W.R., Scott, J., Zheng, W., McNeish, R.E., Holm, N., Hoellein, T.J. and Baranski, E.L. (2019). [Microplastic contamination in karst groundwater systems](#). *Groundwater*, 57(2): 189-196. <https://doi.org/10.1111/gwat.12862>
- Re, V. (2019). [Shedding light on the invisible: addressing the potential for groundwater contamination by plastic microfibers](#). *Hydrogeology Journal*, 27: 2719-2727. <https://doi.org/10.1007/s10040-019-01998-x>
- Rillig, M.C. (2012). [Microplastic in terrestrial ecosystems and the soil?](#) *Environmental Science & Technology*, 46(12): 6453-6454. <https://doi.org/10.1021/es302011r>
- Rillig, M.C., Ziersch, L. and Hempel, S. (2017). [Microplastic transport in soil by earthworms](#). *Scientific Reports*, 7: 1362. <https://doi.org/10.1038/s41598-017-01594-7>
- Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., Muñoz, K., Frör, O. and Schaumann, G.E. (2016). [Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?](#) *Science of the Total Environment*, 550: 690-705. <https://doi.org/10.1016/j.scitotenv.2016.01.153>

- Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D. and Russell, A.E. (2004). [Lost at sea: Where is all the plastic?](#) *Science*, 304(5672): 838. <https://doi.org/10.1126/science.1094559>
- Tufenkji, N. and Elimelech, M. (2004). [Correlation equation for predicting single-collector efficiency in physicochemical filtration in saturated porous media.](#) *Environmental Science & Technology*, 38(2): 529-536. <https://doi.org/10.1021/es034049r>
- Yao, K.-M., Habibian, M.T. and O'Melia, C.R. (1971). [Water and waste water filtration: Concepts and applications.](#) *Environmental Science & Technology*, 5(11): 1105-1112. <https://doi.org/10.1021/es60058a005>
- Zubris, K.A.V. and Richards, B.K. (2005). [Synthetic fibers as an indicator of land application of sludge.](#) *Environmental Pollution*, 138(2): 201-211. <https://doi.org/10.1016/j.envpol.2005.04.013>