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Microplastic Contamination in Agricultural Soil: Sources, Distribution, Impact and Management: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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Abstract

Microplastic pollution of agricultural land has emerged as one of the more consequential, yet under-regulated, forms of soil contamination confronting global food systems. Plastic debris smaller than five millimetres accumulates in farmland through plastic mulching, sewage sludge and compost application, wastewater irrigation, atmospheric deposition and the breakdown of agricultural equipment, and it now appears to occur at concentrations exceeding those reported for marine surface waters. This review synthesises the current understanding of the sources, distribution, environmental fate and ecological consequences of microplastic contamination in agricultural soils, together with the emerging repertoire of management and remediation options. The available evidence indicates that microplastics alter soil structure, water retention and aggregate stability; disturb microbial community composition and nutrient cycling; impair the growth, physiology and reproduction of soil fauna; and reduce germination, biomass and yield in a range of crop species, with effects that vary strongly according to polymer type, particle shape, concentration and soil texture. Microplastics also act as vectors for co-contaminants, including pesticide residues and persistent organic pollutants, and their

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detection in edible plant tissue raises unresolved questions about dietary exposure and human health. Remediation approaches under investigation include biochar and mineral amendments, microbial and enzymatic bioremediation, plant growth-promoting rhizobacteria, phytoremediation and substitution with soil-biodegradable polymers, although none has yet achieved reliable field-scale performance. The review concludes that agricultural microplastic pollution requires coordinated attention from soil science, agronomy, ecotoxicology and policy, and it identifies methodological standardisation, long-term field trials and exposure-realistic toxicology as priorities for future research.

Keywords: Microplastics; agricultural soil; soil health; plastic mulching; soil biota; food chain contamination; bioremediation.

1. Introduction

1.1 Background and Definitions

Microplastics are conventionally defined as synthetic polymer particles, fibres or fragments smaller than five millimetres in their longest dimension, with the sub-category of nanoplastics reserved for particles below one micrometre (Shafea et al., 2023). They arise either as primary particles manufactured at microscopic scale, such as those found in some agrochemical coatings, or as secondary particles produced by the mechanical, photochemical and biological fragmentation of larger plastic items already present in the environment. Since the early 2000s, research attention has concentrated overwhelmingly on the marine compartment, where microplastics were first documented in surface waters and sediments, and where early international assessments catalogued their sources, distribution and likely ecological risk (United Nations Environment Programme, 2016). It is now recognised, however, that terrestrial and, in particular, agricultural systems constitute an equally significant, and in some respects larger, reservoir of plastic contamination (Hoang et al., 2024). The Food and Agriculture Organization of the United Nations estimated that global agricultural value chains consume in the order of 12.5 million tonnes of plastic products annually, encompassing mulching films, greenhouse covers, silage wrap, irrigation pipework, seed coatings and packaging, a substantial proportion of which is neither collected nor recycled at the end of its useful life (Food and Agriculture Organization of the United Nations [FAO], 2021). Recent syntheses also emphasise that the occurrence, ageing, degradation and pollutant-sorption behaviour of microplastics in agricultural soils require soil-specific interpretation rather than direct extrapolation from aquatic systems (Wu et al., 2024).

1.2 The Scale of the Problem in Agricultural Systems

Agricultural soils receive microplastics through numerous, frequently overlapping pathways, and the resulting contamination is now considered to rival, or in some estimates exceed, oceanic loading on a mass basis. A recent global estimate placed the standing stock of microplastics in agricultural soils at between 1.5 and 6.6 million tonnes, one to two orders of magnitude greater than corresponding estimates for the ocean surface (Kedzierski et al., 2023). This discrepancy reflects both the intensity of plastic use in modern farming and the tendency of soils, unlike open water bodies, to act as long-term sinks rather than transient conduits for particulate contaminants. Once incorporated into the soil matrix, microplastics interact with soil minerals, organic matter, microbial biofilms and plant roots over timescales that may extend to decades, and their physical persistence is compounded by resistance to microbial mineralisation (Hoang et al., 2024). The consequences of this accumulation extend across soil physical structure, microbial ecology, faunal health, plant productivity and, potentially, human dietary exposure, and this expanding scope of concern helps explain the sharp growth in primary research on the topic over the past five years. A recent review of mulch films and organic amendments further identifies plastic mulch residues, composted materials and irrigation-related inputs as recurring contributors to soil microplastic loading, while noting that transformation rates depend on polymer properties and soil conditions (Sattar et al., 2025). Soil-focused assessment of health indicators further supports the need to evaluate crop growth, soil fauna, microbial diversity and pollutant interactions together when characterising agricultural microplastic risk (Chang et al., 2024).

1.3 Scope, Research Gap and Objectives

Although a substantial and rapidly growing body of primary research now addresses microplastic contamination of agricultural soil, the literature remains fragmented across distinct disciplinary traditions, spanning soil physics, microbial ecology, plant physiology, ecotoxicology and environmental engineering, with comparatively few syntheses that draw these strands together within a single agronomic frame of reference. Existing reviews tend either to focus narrowly on a single receptor, such as soil microbial communities or crop physiology, or to treat agricultural soils as one setting among several within a broader terrestrial or food-web perspective, leaving practitioners without a consolidated account of what is known, what remains contested, and where management interventions currently stand. This review addresses that gap by providing an integrated account of microplastic contamination specific to agricultural soil systems, extending from the principal sources and pathways of entry, through environmental distribution and fate, to documented impacts on soil physicochemical properties, microbial communities, soil fauna, plant growth and human health, before evaluating the management and remediation strategies currently under development. Recent reviews have also highlighted that field-realistic exposure data, standardised detection protocols and integrated governance frameworks remain insufficiently developed, which supports the need for synthesis across sources, fate, impacts and management in agricultural soil systems (Boctor et al., 2025). The objectives of the review are, first, to characterise and compare the major agricultural sources of microplastic input; second, to synthesise the mechanistic and empirical evidence for microplastic effects across soil, biotic and crop compartments; third, to appraise the feasibility and limitations of proposed remediation approaches; and fourth, to identify priority directions for future research capable of narrowing the gap between laboratory findings and field-realistic understanding.

2. Methods for Literature Selection

2.1 Search Strategy and Databases

This review adopted a narrative rather than a systematic review methodology, reflecting the breadth of the subject matter, which spans soil physics, microbiology, plant science, ecotoxicology and environmental management, and the corresponding need for thematic synthesis rather than a single, narrowly pre-specified outcome measure. Narrative reviews remain a legitimate and widely used vehicle for consolidating evidence across heterogeneous study designs and disciplines, provided the search and selection process is reported transparently; recent methodological guidance for the conduct and appraisal of narrative reviews informed the structure of the present search (Baethge et al., 2019). Literature was retrieved from Web of Science, Scopus and Google Scholar as core multidisciplinary databases, supplemented by six field-specific indexing resources selected for their coverage of soil science, agronomy and environmental toxicology, namely PubMed, AGRICOLA, CAB Abstracts, GreenFILE, the Directory of Open Access Journals and SciFinder. Search strings combined the core term "microplastic*" with soil- and agriculture-specific qualifiers, including "agricultural soil", "farmland", "cropland", "plastic mulch*", "soil biota", "earthworm*", "soil microb*", "crop uptake" and "remediation", connected using Boolean operators and truncation to capture morphological variants.

2.2 Date Range and Inclusion Criteria

The search covered literature published between January 2015 and April 2026. The start date was chosen because sustained empirical research into microplastics as a terrestrial, and specifically agricultural, contaminant did not gain momentum until the mid-2010s; before that point, the great majority of published work addressed marine and freshwater compartments. Records published earlier than this threshold were included only where they represented foundational methodological or conceptual contributions of continuing relevance, such as early studies on biodegradable mulch film degradation. Eligible sources comprised original research articles and review articles published in peer-reviewed academic journals, together with authoritative technical reports from recognised international and intergovernmental bodies, including the Food and Agriculture Organization of the United Nations and the United Nations Environment Programme, cited where no peer-reviewed equivalent existed and accompanied by a verifiable web address. Books, conference proceedings, pre-print manuscripts, trade publications, patents and non-peer-reviewed grey literature were excluded, with the sole exception of the institutional reports noted above.

2.3 Screening and Selection Procedure

Titles and abstracts retrieved from the database searches were screened for topical relevance to microplastic occurrence, behaviour or effects within agricultural or arable soil systems; studies confined to purely marine, freshwater or urban non-agricultural settings were excluded unless they offered directly transferable mechanistic insight. Duplicate records identified across databases were consolidated using reference-management software prior to full-text screening. Only English-language publications were retained, reflecting both the predominance of English-language reporting in this field and practical constraints on translation. Where multiple studies addressed a similar experimental question, preference during synthesis was given to more recent, higher-impact or more frequently cited studies, and to those employing field or mesocosm designs over short-term laboratory assays alone, in order to privilege findings with greater ecological realism. Reference lists of key reviews identified during the search were hand-searched to capture additional influential primary studies that database searching alone might have missed.

2.4 Summary of Search Strategy

Table 1 summarises the databases, search terms, date range and inclusion and exclusion criteria applied during the literature selection process described above.

Table 1. Summary of the literature search strategy

Element	Specification
Core databases	Web of Science, Scopus, Google Scholar
Field-specific databases	PubMed, AGRICOLA, CAB Abstracts, GreenFILE, DOAJ, SciFinder
Core search term	microplastic*
Qualifying terms	agricultural soil, farmland, cropland, plastic mulch*, soil biota, earthworm*, soil microb*, crop uptake, remediation
Date range	January 2015–April 2026
Language	English only
Inclusion criteria	Peer-reviewed original research and review articles; authoritative institutional reports with verifiable URL
Exclusion criteria	Books, conference proceedings, pre-prints, trade publications, patents, non-peer-reviewed grey literature
Review type	Narrative, thematic synthesis

Source: compiled by the author following the search procedure described in Section 2.1–2.3, informed by Baethge et al. (2019)

3. Sources and Pathways of Microplastic Entry into Agricultural Soils

3.1 Plastic Mulching and Greenhouse Films

Plastic mulching is widely regarded as the single most significant intentional source of microplastic contamination in intensively managed cropland. Polyethylene film is applied to suppress weeds, conserve soil moisture and elevate soil temperature, but recovery rates after harvest are consistently incomplete, and residual fragments undergo progressive embrittlement through ultraviolet exposure and mechanical abrasion by tillage equipment, generating microplastic particles that accumulate in the topsoil over repeated cropping cycles (Hoang et al., 2024). A United Kingdom survey of soils used for potato and carrot production found substantially higher microplastic concentrations where plastic crop covers had been used, with mean values markedly greater at sites with a history of cover use compared with uncovered fields, providing direct field-based confirmation of the mulching pathway under temperate farming conditions (Cusworth et al., 2024). Soil-biodegradable alternatives such as polylactic acid and polybutylene adipate terephthalate are increasingly promoted as a substitute for conventional film, but complete mineralisation is not always achieved within a single growing season, and transient microplastic fragments may still be generated during the degradation process itself, a distinction that is now attracting closer regulatory scrutiny (Koitabashi et al., 2012).

3.2 Sewage Sludge, Compost and Organic Amendments

The application of sewage sludge, biosolids and municipal compost as soil conditioners represents a further major, and frequently underappreciated, pathway. Wastewater treatment processes remove only a proportion of the microplastic load present in influent, and much of the remainder becomes concentrated within the sludge fraction, which is subsequently applied to agricultural land as a low-cost source of organic matter and nutrients

(Shafea et al., 2023). Because such practices are typically repeated over successive seasons, the cumulative loading of microplastics associated with sludge amendment can substantially exceed single-year contamination estimates, and this pathway is considered particularly important in regions where sludge reuse in agriculture is actively promoted as a resource-recovery strategy.

3.3 Irrigation, Atmospheric Deposition and Other Diffuse Sources

Irrigation with untreated or partially treated wastewater, and with water drawn from rivers or reservoirs already carrying a microplastic burden, provides an additional and largely uncontrolled entry route, particularly in water-scarce regions where reclaimed water use is encouraged for agronomic reasons (Tian et al., 2022). Atmospheric deposition constitutes a further diffuse but ubiquitous source, delivering airborne fibres and fragments derived from urban and industrial activity even to soils with no direct history of plastic use, a mechanism that helps explain the detection of microplastics in remote and non-mulched agricultural fields (Sharmin et al., 2024). Further inputs arise from the wear of agricultural machinery tyres, the degradation of polymer-coated fertiliser and pesticide formulations, plastic packaging waste and informal littering, together producing a composite and highly heterogeneous contamination signature that varies markedly with land-use intensity, cropping system and regional waste-management infrastructure (He et al., 2023).

Table 2 summarises the principal source categories, their typical polymer composition and the mechanisms by which each contributes to soil microplastic loading.

Table 2. Principal sources and pathways of microplastic entry into agricultural soils

Source category	Typical polymer(s)	Entry mechanism
Plastic mulching and greenhouse films	Polyethylene, polylactic acid, polybutylene adipate terephthalate	Photodegradation and mechanical fragmentation of residual film
Sewage sludge and biosolids	Mixed polymers (polyester, polyethylene, polypropylene)	Incomplete removal during wastewater treatment; direct soil application
Compost and organic fertiliser	Mixed polymers, packaging residues	Contamination of feedstock; incorporation during composting
Wastewater and reclaimed water irrigation	Mixed polymers, fibres	Suspended particles delivered in irrigation water
Atmospheric deposition	Fibres (polyester, acrylic), fragments	Wind-borne transport and deposition
Agricultural machinery and packaging	Rubber, polyvinyl chloride, polypropylene	Tyre wear, equipment abrasion, packaging degradation

Source: synthesised from Hoang et al. (2024), Shafea et al. (2023), Tian et al. (2022) and Sharmin et al. (2024)

4. Distribution and Environmental Fate

Once introduced into the soil profile, microplastics are subject to a complex set of physical and biological processes governing their vertical and lateral redistribution. Particles are commonly concentrated within the upper fifteen to thirty centimetres of the profile, corresponding to the depth of conventional tillage, although downward migration into deeper horizons occurs through macropore flow, bioturbation by soil fauna and preferential transport along root channels, with smaller particles and fibres exhibiting greater mobility than larger fragments (Sharmin et al., 2024). Global synthesis of available field data indicates that concentrations vary by several orders of magnitude according to land use, proximity to urban and industrial centres, irrigation source and mulching history, with China, owing to its extensive reliance on plastic film mulching, contributing a disproportionate share of the reported global stock (Kedzierski et al., 2023). Environmental ageing, driven by ultraviolet radiation, oxidation and microbial colonisation, progressively alters particle surface chemistry, increasing polarity and adsorption capacity for co-contaminants while simultaneously rendering particles more brittle and prone to further fragmentation into the nanoplastic size range, a process with implications for both ecotoxicity and analytical detectability (Hoang et al., 2024). Soil texture also exerts a substantial influence on retention and transport: fine-textured soils tend to retain low-density, flexible polymers such as polyethylene and polypropylene through adsorption to reactive clay minerals, whereas coarser soils permit greater particle mobility and a correspondingly higher risk of leaching towards groundwater (Zhao et al., 2022).

5. Impacts on Soil Physicochemical Properties

5.1 Structure, Aggregation and Hydraulic Behaviour

Microplastic incorporation measurably alters the physical architecture of agricultural soil. Depending on particle shape, size and concentration, microplastics can either reinforce or disrupt soil aggregate formation: fibrous particles frequently enhance aggregate stability through a binding effect analogous to that of plant roots, while rigid fragments tend to create discontinuities that weaken aggregate cohesion (Zhao et al., 2022). These structural changes translate into altered hydraulic behaviour. Several studies report reductions in soil water retention and saturated hydraulic conductivity following microplastic addition, with the magnitude and even the direction of the effect strongly dependent on soil texture, since clay-rich and sandy soils respond quite differently to the same polymer treatment (Neubert et al., 2025). Because plant-available water is a first-order determinant of crop performance, these hydraulic perturbations carry direct agronomic significance, particularly in water-limited production systems.

5.2 Chemical Properties and Pollutant Vectoring

Microplastic presence has also been associated with measurable shifts in soil pH, generally modest in magnitude but detectable across a range of polymer types and exposure durations, alongside changes in soil organic carbon dynamics and nitrogen transformation processes that carry implications for the broader carbon and nitrogen balance of contaminated agricultural soils (Zheng et al., 2025). Horticultural soils, which often receive intensive plastic mulching combined with frequent irrigation, have been highlighted as a setting of particular eco-toxicological concern in this respect (Sharma et al., 2023). A further chemical concern arises from the capacity of microplastic surfaces, particularly following environmental ageing, to adsorb hydrophobic organic pollutants, effectively functioning as vectors that concentrate and redistribute these co-contaminants within the soil profile and potentially enhance their bioavailability to soil organisms; a similar vectoring role has also been suggested for heavy metals in the wider literature on soil-plastic interactions (Fajardo et al., 2022).

Table 3 summarises the principal categories of physicochemical effect reported in the literature.

Table 3. Summary of documented microplastic effects on agricultural soil physicochemical properties

Soil property	Reported direction of effect	Key influencing factors
Aggregate stability	Variable; increased by fibres, decreased by rigid fragments	Particle shape, polymer type
Water retention and hydraulic conductivity	Generally decreased	Soil texture, particle size
Soil pH	Modest shifts, generally minor	Polymer type, exposure duration
Soil organic carbon and nitrogen cycling	Altered storage and turnover, with implications for carbon and nitrogen balance	Polymer biodegradability
Adsorption of co-contaminants	Increased, particularly after ageing	Surface ageing, particle surface area

Source: synthesised from Zhao et al. (2022), Neubert et al. (2025), Sharma et al. (2023), Zheng et al. (2025) and Fajardo et al. (2022)

6. Impacts on Soil Microbial Communities and Biogeochemical Cycling

Microplastics interact intimately with the soil microbiome, providing novel colonisable surfaces, sometimes termed the plastisphere, that select for particular bacterial and fungal taxa distinct from those dominant in the surrounding bulk soil (Li et al., 2023). Meta-analytical evidence indicates that the direction and magnitude of microbial response depend heavily on particle size, with microplastics in the strict sub-five-millimetre range sometimes suppressing microbial functional diversity, while larger plastic residues can, counterintuitively, stimulate microbial biomass by supplying a labile carbon substrate that pioneer degrading taxa are able to exploit (Li et al., 2023). Dissolved organic matter released during the degradation of biodegradable microplastics further modifies microbial metabolic activity, and in some cases accelerates the photo-ageing of coexisting conventional microplastics through a synergistic chemical interaction (Ouyang et al., 2023).

These community-level shifts propagate into altered biogeochemical cycling. Nitrogen transformation processes, including nitrification, denitrification and ammonia volatilisation, are consistently reported to be disrupted by microplastic contamination, with consequences for nitrogen-use efficiency and, in some experimental systems, measurable reductions in crop nitrogen uptake and yield (Sarfraz et al., 2025). A dedicated review of the nitrogen cycle concluded that microplastic effects on nitrogen-cycling microorganisms are polymer- and dose-dependent, but that the balance of evidence points towards a net disruption of nitrogen-use efficiency in contaminated soils (Riveros et al., 2022). Broader synthesis of the state of knowledge regarding micro- and nanoplastic effects on soil nutrient cycling similarly identifies consistent, if mechanistically incompletely understood, interference with enzyme-mediated carbon, nitrogen and phosphorus transformations across contaminated soils (Salam et al., 2023). Taken together, these findings support the characterisation of microplastic contamination as a genuine driver of soil ecosystem-level change rather than a merely inert physical presence, a conclusion echoed in recent editorial synthesis of the field (Zheng et al., 2025).

7. Impacts on Soil Fauna

Soil invertebrates, and earthworms in particular, have served as the principal model organisms for assessing the ecotoxicological consequences of microplastic exposure in terrestrial systems, owing to their ecological importance as soil engineers and their direct ingestion of soil particles during burrowing and feeding. Bibliometric analysis of this literature confirms that oxidative stress represents the characteristic toxicological response, with elevated microplastic content in soil associated with impaired growth, neural disturbance and DNA damage in earthworms once concentrations exceed a threshold in the region of one-tenth of one per cent by soil mass (Guo et al., 2023). A parallel bibliometric assessment of global research activity on micro- and nanoplastic toxicity to earthworms confirms the rapid expansion of this literature in recent years and identifies mortality, reduced body mass and impaired cocoon production as the most frequently reported toxicological endpoints across laboratory exposure studies (Gong et al., 2023). Reported effects vary according to polymer identity, particle size and exposure duration, and combined exposure to microplastics and co-occurring agrochemicals, such as pesticides, has in several studies produced toxicity exceeding that predicted from either stressor alone, pointing towards a synergistic interaction of practical relevance to real agricultural exposure scenarios rather than the single-contaminant conditions typical of controlled laboratory assays.

8. Impacts on Plant Growth, Crop Quality and Food Chain Transfer

8.1 Germination, Root and Shoot Development

Microplastic exposure affects terrestrial plants across the full developmental sequence, from seed germination through vegetative growth to reproduction and final yield, although the direction of effect is far from uniform across the literature. Mechanistically, two complementary pathways appear responsible for growth impairment: physical obstruction of pores in the seed coat or root epidermis, which interferes with water and nutrient uptake, and induction of soil desiccation through microplastic-mediated changes in soil structure that increase surface cracking (Jia et al., 2023). Root tissues are disproportionately affected relative to shoot tissues, with reported reductions in root elongation, root biomass and root activity documented across multiple crop species including wheat, broad bean and onion, reflecting the direct physical interface between root systems and the surrounding contaminated soil matrix (Jia et al., 2023). Reviews addressing the broader terrestrial plant literature similarly conclude that plant growth and physiological function are, on balance, more often impaired than enhanced by microplastic exposure, although stimulatory effects on root growth have occasionally been reported, and there is a tentative indication that monocotyledonous species may be somewhat less sensitive than dicotyledonous species (Wong & Taylor, 2025).

8.2 Physiological and Biochemical Disturbance

At the physiological level, microplastic exposure has been linked to disruption of photosynthetic efficiency, generation of reactive oxygen species, lipid peroxidation and activation of antioxidant defence systems including superoxide dismutase, catalase and peroxidase activity, with the magnitude of response varying by polymer type, particle concentration and plant species (Jadhav & Medyńska-Juraszek, 2024). Beyond this direct physiological disturbance, microplastics have also been shown to modify plant allelopathic interactions, altering leaf chemistry in ways that influence competitive relationships between co-occurring native and invasive plant species, an effect with implications for weed management and agroecosystem composition that extend beyond the crop plant itself (Yuan et al., 2024).

8.3 Uptake, Translocation and Food Chain Relevance

A particularly consequential body of evidence concerns the capacity of nanoscale plastic particles to be taken up by plant root systems and translocated to above-ground tissue, including edible portions of food crops, thereby establishing a direct pathway for microplastic entry into the human food chain (Jadhav & Medyńska-Juraszek, 2024). This uptake pathway, combined with documented effects on soil-borne plant pathogen dynamics and pesticide behaviour in contaminated soil, underscores that the agronomic significance of microplastic contamination extends beyond yield reduction alone to encompass food safety considerations that remain incompletely characterised.

Table 4 summarises reported effects of microplastic exposure across key stages of crop development.

Table 4. Summary of reported microplastic effects on crop growth and physiology

Developmental stage or process	Commonly reported effect	Representative crops studied
Seed germination	Variable; inhibition or, less commonly, stimulation	Wheat, chickpea, ryegrass
Root elongation and biomass	Predominantly reduced	Wheat, broad bean, onion
Shoot growth and biomass	Generally reduced at high concentration	Maize, tomato, lettuce
Photosynthetic efficiency	Reduced via pigment loss and photosystem impairment	Maize, mangrove, lettuce
Oxidative stress markers	Elevated (reactive oxygen species, malondialdehyde)	Cherry radish, tomato, rice
Root uptake and translocation	Documented for nanoscale particles	Lettuce, wheat, radish

Source: synthesised from Jia et al. (2023), Wong and Taylor (2025) and Jadhav and Medyńska-Juraszek (2024)

9. Human Health Implications

The detection of microplastics within edible plant tissue, combined with their established presence in irrigation water, soil dust and processed food products, situates agricultural soil contamination within a broader human exposure pathway that extends from the field to the dining table. Human dietary microplastic exposure remains difficult to quantify with precision, owing to the absence of harmonised detection protocols across studies, but ingestion through food and drinking water is generally regarded as the dominant exposure route, supplemented by inhalation and limited dermal contact (He et al., 2023). Microplastics and associated additive chemicals, including plasticisers such as bisphenol A, have been detected in human blood, placental tissue and other internal compartments, and laboratory evidence points towards oxidative stress, inflammatory responses and disruption of the gut microbiome as plausible mechanisms of toxicity, although a causal link between agricultural soil-derived dietary exposure and specific clinical outcomes in humans has not been established (Thompson et al., 2024). Populations in direct and repeated contact with contaminated agricultural soil, including farm workers, represent an occupational exposure pathway that has received comparatively little dedicated attention to date (Sharmin et al., 2024). Probabilistic health risk assessments applied to non-mulched agricultural soils have nonetheless indicated that current soil-borne exposure levels remain, in most sampled contexts, below thresholds of acute concern, even as the long-term, cumulative significance of chronic low-dose exposure remains an open and actively debated question within the field (Sharmin et al., 2024).

10. Management and Remediation Strategies

10.1 Source Reduction and Substitution

The most direct route to limiting agricultural microplastic contamination lies in reducing the input of new plastic material, through improved collection and recycling of conventional mulch film, substitution with certified soil-biodegradable polymers designed to mineralise fully rather than merely fragment, and the adoption of alternative agronomic practices, such as cover cropping, that reduce reliance on plastic mulching altogether (Food and Agriculture Organization of the United Nations, 2021). Evidence on the performance of biodegradable mulch alternatives remains mixed, since incomplete or delayed degradation under field conditions can itself generate transient microplastic fragments before full mineralisation is achieved, indicating that substitution alone does not guarantee elimination of the underlying problem without complementary attention to degradation kinetics under local soil and climatic conditions (Koitabashi et al., 2012).

10.2 Physicochemical and Biological Remediation

Among remediation technologies currently under investigation, biochar-based soil amendment has attracted particular attention on account of its low cost, compatibility with existing fertilisation infrastructure and demonstrated capacity to adsorb microplastic particles while simultaneously improving soil microbial biomass and nutrient cycling, positioning it as one of the more field-scalable remediation options presently available (Thapliyal et al., 2024). Microbial and enzymatic bioremediation approaches, exploiting naturally occurring or engineered plastic-degrading microorganisms and plant growth-promoting rhizobacteria, represent a further promising avenue, although most supporting evidence to date derives from controlled laboratory or pot-scale experiments rather than open-field trials, and degradation rates achieved under realistic soil conditions remain considerably slower than would be required for meaningful remediation within practical agronomic timeframes (Thapliyal et al., 2024). Phytoremediation strategies, which exploit the capacity of certain plant species and their associated rhizosphere microbiota to accumulate, immobilise or facilitate the breakdown of soil microplastics, offer a complementary, low-input option, though species selection and long-term efficacy under field conditions require further validation before widespread adoption can be recommended.

10.3 Policy and Governance Considerations

Effective management of agricultural microplastic contamination ultimately depends on coordinated policy intervention alongside technical remediation, encompassing extended producer responsibility schemes for agricultural plastic products, standardised protocols for the collection and recycling of used mulch film, and regulatory frameworks governing the composition and labelling of biodegradable agricultural plastics, an approach explicitly advocated in recent international guidance on sustainable plastics management in agriculture (Food and Agriculture Organization of the United Nations, 2021). The absence of harmonised international standards for the extraction, quantification and reporting of soil microplastics continues to constrain both scientific comparability across studies and the development of evidence-based regulatory thresholds, and represents a governance gap of comparable importance to any single remediation technology.

Table 5 summarises the principal management and remediation strategies discussed above, together with their current stage of development and key limitations.

Table 5. Summary of management and remediation strategies for microplastic-contaminated agricultural soils

Strategy	Mechanism	Current status and limitations
Source reduction and improved recycling	Reduced new plastic input	Feasible but dependent on collection infrastructure
Substitution with biodegradable mulch	Complete mineralisation in place of persistent fragmentation	Field degradation rates variable; transient fragments possible
Biochar and mineral amendment	Adsorption and immobilisation of particles	Field-scalable; long-term efficacy under field conditions still being established
Microbial and enzymatic bioremediation	Enzymatic depolymerisation by degrading microorganisms	Promising but largely laboratory-scale; slow field degradation rates
Phytoremediation and rhizosphere-assisted removal	Plant and microbial uptake, immobilisation or breakdown	Low input cost; species selection and scale-up require further validation
Policy and extended producer responsibility	Systemic reduction of plastic use and improved end-of-life management	Requires international coordination; standardisation still lacking

Source: synthesised from FAO (2021), Thapliyal et al. (2024) and Koitabashi et al. (2012)

11. Future Directions

Progress in understanding and managing agricultural microplastic contamination will depend substantially on resolving several methodological limitations that currently constrain cross-study comparison. Foremost among these is the absence of standardised protocols for microplastic extraction, quantification and reporting, which continues to produce concentration estimates that differ by orders of magnitude between studies employing different separation and detection methods, undermining confidence in global synthesis efforts of the kind attempted by Kedzierski et al. (2023). Research would benefit from a shift away from short-term, single-species, high-concentration laboratory exposures towards long-term field trials conducted at environmentally realistic contamination levels, capable of capturing cumulative effects across multiple cropping cycles and interactions with co-occurring agricultural stressors such as drought, salinity and agrochemical residues. Greater attention should also be directed towards nanoplastic fractions, which are analytically far more difficult to detect and quantify than their microplastic counterparts but may carry disproportionate toxicological and food-chain significance given their capacity for cellular uptake and translocation (Thompson et al., 2024). Development of predictive models linking polymer type, particle morphology, soil texture and climatic conditions to expected ecological and agronomic outcomes would help prioritise remediation investment towards the settings of greatest risk, while breeding programmes aimed at developing crop varieties with reduced sensitivity to microplastic-induced stress represent a longer-term but potentially high-value avenue of applied research. Closer integration between soil science, agronomy, toxicology and food safety regulation will ultimately be required to translate this rapidly expanding evidence base into coherent, enforceable standards governing acceptable microplastic loading in agricultural soils and produce.

12. Conclusions

Microplastic contamination of agricultural soil has moved, within little more than a decade, from a peripheral research curiosity to a recognised and quantitatively substantial component of global soil pollution. The evidence reviewed here indicates that plastic mulching, sewage sludge and compost application, wastewater irrigation and atmospheric deposition together deliver a heterogeneous but persistent burden of microplastic particles into farmland, where they measurably alter soil structure and hydraulic behaviour, disturb microbial community composition and nutrient cycling, impair the growth and reproduction of soil fauna, and reduce germination, biomass and yield across a range of crop species. The magnitude and even direction of these effects depend heavily on polymer identity, particle morphology, concentration and soil type, which precludes simple generalisation but still points consistently towards net detriment to soil health and agricultural productivity under the conditions most commonly studied. Emerging evidence of plant uptake and translocation of nanoscale particles, together with detection of microplastics and associated additive chemicals in human tissue, extends the significance of agricultural soil contamination beyond the field itself into questions of food safety and public health that remain far from fully resolved. Management responses spanning source reduction, biochar and biological remediation, and improved governance of agricultural plastics offer grounds for cautious optimism, but none has yet demonstrated reliable, cost-effective performance at field scale, and this gap between promising early-stage findings and dependable field practice is likely to define the direction of the field for some years to come.

13. Limitations

This review is subject to several limitations inherent to its narrative rather than systematic design. The literature search, while extensive, was restricted to English-language publications, which may have excluded relevant regional research published in other languages, particularly from parts of Asia and Latin America where agricultural plastic use is intensive. The narrative approach, although well suited to synthesising a methodologically and disciplinarily heterogeneous evidence base, does not incorporate formal quality appraisal or meta-analytic pooling of effect sizes, so the conclusions drawn here should be read as a qualitative synthesis of prevailing evidence rather than a quantitatively weighted assessment. The underlying primary literature itself remains dominated by short-term, controlled laboratory and pot-scale experiments conducted at microplastic concentrations often exceeding those documented under realistic field conditions, which limits the extent to which reported effects can be assumed to translate directly to commercial farming settings. Substantial inconsistency in the extraction, quantification and reporting methods used across studies further complicates direct comparison of the concentration and effect data cited throughout this review, a limitation that reflects a broader methodological challenge facing the field as a whole rather than a shortcoming specific to this synthesis.

Declaration of AI Use

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Competing Interests

Authors have declared that no competing interests exist.

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