Plastic Footprint Guidelin

Module on microplastic – agriculture

Version 1. December 2024

Convened by EA – Earth Action • www.plasticfootprint.earth

Objective of this module

The aim of this module is to evaluate the current state of the science and available methodologies for evaluating the impact of microplastics derived agriculture.

The module brings forward a first calculation approach based on available data. Objectives are:

- List the publications and identify how they can be used to feed the inventory methodology
- Identify the fluxes and gather rationales to prioritize their relative importance
- For fluxes for which data is available propose a first draft for calculation routes and secondary datasets
- Objective 2025:

  Link the methodology to impact module

  Refine the methodology including more sources and characteristics

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Plastic pollution in agriculture

How plastics end up in agricultural soil

An overview of plastic leakage sources in agriculture

Plastic use in agriculture has grown significantly over the past decades, driven by its affordability, durability, and utility in enhancing productivity. However, these benefits come with environmental concerns, particularly plastic leakage into ecosystems, where it can persist for decades, causing harm to soil health, water quality, and biodiversity. Plastic leakage from agricultural soils can originate from **direct sources**, where plastic is intentionally introduced but inadequately managed, or **indirect sources**, where plastic enters the environment unintentionally through degradation or secondary contamination.

Direct and obvious sources :

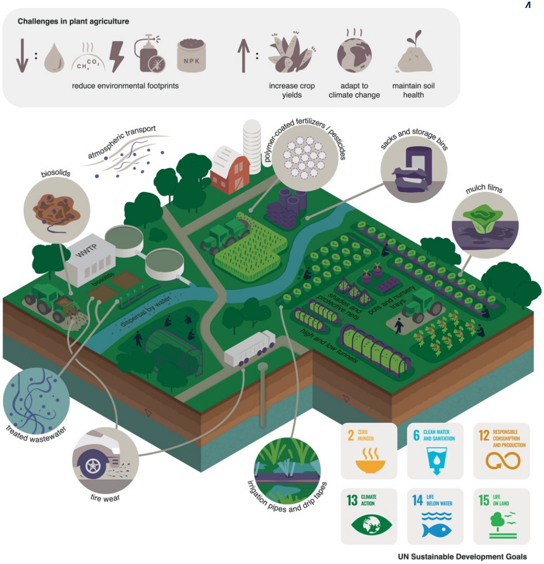
- Mulching films
- Protecting nets
- Greenhouses
- Irrigation pipes
- Bags and other packagings

These macroplastics break down into microplastics over time due to weathering, mechanical stress, and biological activity.

Indirect and less obvious sources :

- Organic fertilizer products (composts, manure and WWTP sludges)
- Fertilizer/Pesticide Encapsulants
- Water
- (Tyre abrasion)

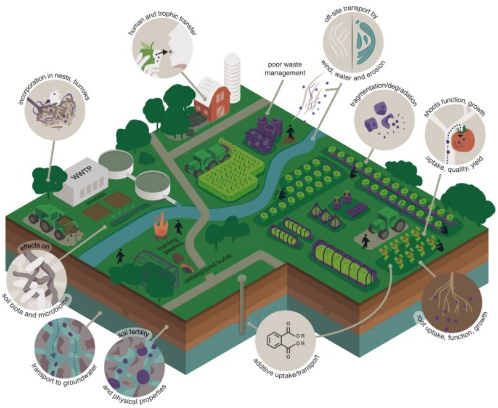
PFN modules Micro textile and Tyres



[1] Hofmann, T., Ghoshal, S., Tufenkji, N. et al. Plastics can be used more sustainably in agriculture. Commun Earth Environ 4, 332 (2023). https://doi.org/10.1038/s43247-023-00982-4

What are the negative effects and risks associated to plastics contamination in agricultural soils?

- Microplastics are not the only stressors acting on agricultural ecosystems. Many global change stressors are acting concurrently on agricultural ecosystems, including physical (e.g., warming), chemical (e.g., pesticides), and biological (e.g., invasive plant species or weeds) stressors. Recent work suggests that the combined pressures and the high number of factors acting on agricultural soils can lead to unpredictable effects in the soil ecosystem [2,3]
- Microplastics can be absorbed by organisms, disrupting microbiome functions. Understanding the potential for plastics and leached additives to accumulate in plants and enter the food chain is crucial for safeguarding food safety and human health.
- Microplastics have been shown to negatively affect the growth of crops and animals (e.g., ciliates, flagellates), and cause soil bacterial community structure dysbiosis. [4,5]
- Leaching of additives from plastics increases the chemical burden on soils. The consequences of a long-term release of chemicals due to the degradation of plastics in soils are unknown [6]



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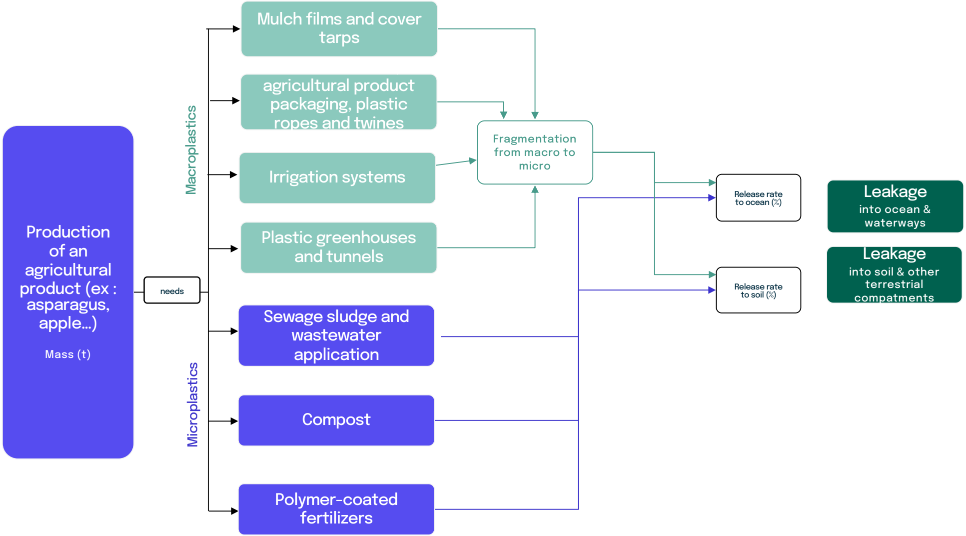
System map for microplastic in agriculture

The path of microplastic leaks for producing an agricultural product



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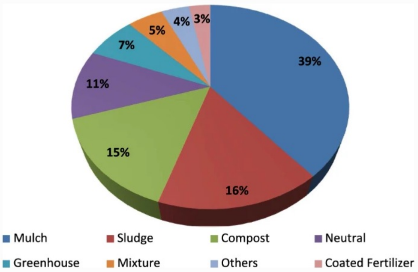
Overview of methodologies

A review of current methodologies from the scientific literature

Research in micoplastics and agriculture

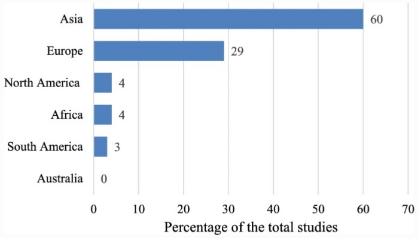
- Plastic is found in many types of crops and agricultural land: arable lands, paddy lands, uplands, irrigation, and greenhouse soils.
- Significant sources of plastic contamination in the agricultural soils includes mulching, sludge and compost placement, and greenhouses abandonment.
- Most research studies have been carried in Asia and Europe.
- The amount of microplastics released depend on:
  - The type of source
  - The geographical region
  - The crop category
  - The type of site (urban area versus remote countryside)
  - Differences in land management, soil, geomorphology,
- Models do often not take into account the size, type of polymer or shape of microplastics. The databases used contain large uncertainties and the method only gives estimates.

Fig. 2



Sources of microplastics in agricultural soils (*n* = 120)

Fig. 1



Worldwide distribution of plastics studies conducted on agricultural land (*n* = 120)

Sa'adu et al., 2023

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Characteristics of plastic pollution in agricultural soil

Soil contamination varies along soil profile with a clear decrease from -20cm to -90cm. (Kedzierski et al., 2023)

Concentrations of microplastics in agricultural soils increase over time and the application of organic and inorganic fertilisers are significant contributors of microplastics. (Cusworth et al., 2024)

Global median stock of microplastics in soils could be of the order of 3.6 Mt., which is one to two orders of magnitude higher than what has been estimated for microplastic stocks at the ocean surface. (Kedzierski et al., 2023)

Methotolodies and measurement methods vary accross the litterature leading to different values and conclusions. Buks et al (2020).

impact of historical practices on soil contamination: soils in many agricultural regions now contain significant plastic residues accumulated over the decades(Cusworth et al., 2024)

Country	Plastic source	Soil type	Crop(s)	Abundance		Composition	References
				Macro	Micro		
Hungary	Greenhouse	Arable land	Tomatoes	6.4 kg h^{-1}	225 ± 61.69 pieces kg^{-1}	PE, PVC, and PP	[36]
China	Mulch	Arable land	Maize	6796 ± 1070 pieces m^{-2}	8885 and 2899 pieces kg^{-1}	PE, PP, and PET	[57]
China	Mulch	Upland land	Maize		754 ± 477 items kg^{-1}	PP, PE, PET, and PES	[52]
China	Sludge	Paddy land	Rice and wheat		149.2 ± 52.5, 68.6 ± 21.5, and 73.1 ± 15.4 particles kg^{-1}	PES, PP, and PS-AC	[22]
China	Plastic gauze	Arable land	NA		1629.68 tons $year^{-1}$	NA	[26]
Japan	Coated fertilizer	Paddy land	Rice		144 mg kg^{-1}	PE	[37]
Thailand	Mix	Mix	Cabbage, pumpkin, guava, etc.		12–117 items m^{-2}	PE, LDPE, PP, and PS	[59]
India	Mulch	Arable land	Tomatoes		37.97%, 35.07%, and 36.99% plastic residue	NA	[61]
Korea	Mix	Mix	Rice and vegetables		664 pieces kg^{-1}	PE and PP	[66]
Switzerland	Mulch	Drainage water	Vegetables		10.5 ± 9.5 N L^{-1}		[70]
Germany	Sludge	Arable land	NA		14.6 MP g^{-1}	PES, PA, PVC, PAN, etc.	[51]
Greece	Film	Greenhouse	Watermelon and tomatoes		301 ± 140 and 69 ± 38 items kg^{-1}	PE and BMF	[54]
Spain and Netherland	Mix	Mix	Broccoli, celery, and watermelon		2242 ± 984 and 888 ± 500 MPs kg^{-1}	NA	[43]
Switzerland	Organic compost	Arable land	NA		22.4 ± 3.3 tons $year^{-1}$	NA	[71]
Tanzania	N.A	Irrigation land	NA	0.5–5.5 kg	0.21–1.50 items g^{-1}	PET, HDLE, LPE, PS, etc.	[53]
Mauritius	Mix	Arable land	Vegetables		320.0 ± 112.2 and 420.0 ± 244.0 particles kg^{-1}	PP and PA	[56]
Tunisia	Mix	Mix	NA		13.21 ± 0.89 to 852.24 ± 124.2 items kg^{-1}	PEVA, PE, PBAT, and PP	[25]
Chile	Mix	Mix	NA		306 ± 360–184 ± 266 particles kg^{-1}	PE, PP, and PS	[62]
Canada	Biosolid	Arable land	NA		4.1 × 1011 and 1.3 × 1012 particles	PE, PP, PS, etc.	[58]
Mexico	Mulch	Arable land	NA		400–2000 particles kg^{-1}	LDPE	

Sa’adu et al., 2023

Methods by sources

These methods can be used for other regions and adapted when more knowledge and data become available.

Brandes, Elke, Martin Henseler, and Peter Kreins, 2021. Identifying Hot-Spots for Microplastic Contamination in Agricultural Soils–a Spatial Modelling Approach for Germany. Environmental Research Letters 16, 104041. https://doi.org/10.1088/1748-9326/ac21e6.

1) Estimations of the amounts of MP entering agricultural soils through sewage sludge in Germany

Method : $\mathrm{MP}_{i2016}^{SL} = C_{2016}^{SL} \times M_{i2016}^{SL}$. (1)

MP masses in mg = national mean MP concentration in sewage sludge in wt% (0,56 wt% for Germany) * sewage sludge masses produced for agricultural per region
Could be used as follows :
- Establish secondary data by geographical region on the **MP concentration in sewage sludges**
- Establish secondary data by geographical region on the **mass of sewage production**
- Establish secondary data by geographical region on the **proportion of sewage sludge discharged into agricultural soil** (the PFN already has secondary data?)

2) Estimations of the amounts of MP entering agricultural soils through compost in Germany

Method : $\mathrm{MP}_{i2016}^{\mathrm{CO}} = M_{i2016}^{\mathrm{CO}} \times C^{\mathrm{CO}}$. (9)

MP masses in mg = compost amounts produced for agricultural use per region * national mean MP concentration in compost wt% (0,037 wt% for Germany)
Could be used as follows :
- Establish secondary data by geographical region on the **MP concentration in compost**
- Establish secondary data by geographical region on the **mass of compost production**

Mulch films and cover tarps

Brandes, Elke, Martin Henseler, and Peter Kreins, 2021. Identifying Hot-Spots for Microplastic Contamination in Agricultural Soils–a Spatial Modelling Approach for Germany. Environmental Research Letters 16, 104041. https://doi.org/10.1088/1748-9326/ac21e6.

3) Estimations of the amounts of MP entering agricultural soils through mulch films and cover tarps **in Germany**

Method :

$$\mathrm{MP}^{SC}_{i2012} = A^{SC}_{i2012} \times AP^{SC}_{2012} \times L^{SC} \times FM^{SC}, \qquad (13)$$

Crop category	AP^{SC}_{2012}	L^{SC}	TH (m)	D^{LDPE} (kg m^{-3})	FM^{SC} (kg ha^{-1})
ASP	1.0	0.0010	0.000 100	917.5	917.500
STR	0.5	0.0027	0.000 040	917.5	367.000
CUC	1.0	0.0094	0.000 030	917.5	275.250
LET	0.5	0.0100	0.000 025	917.5	229.375
EPO	1.0	0.0100	0.000 025	917.5	229.375

MP masses in mg = area of the speciality crop category grow … d * loss factor * mass of foil per ha (= thickness * 10 000 * D_LDPE)

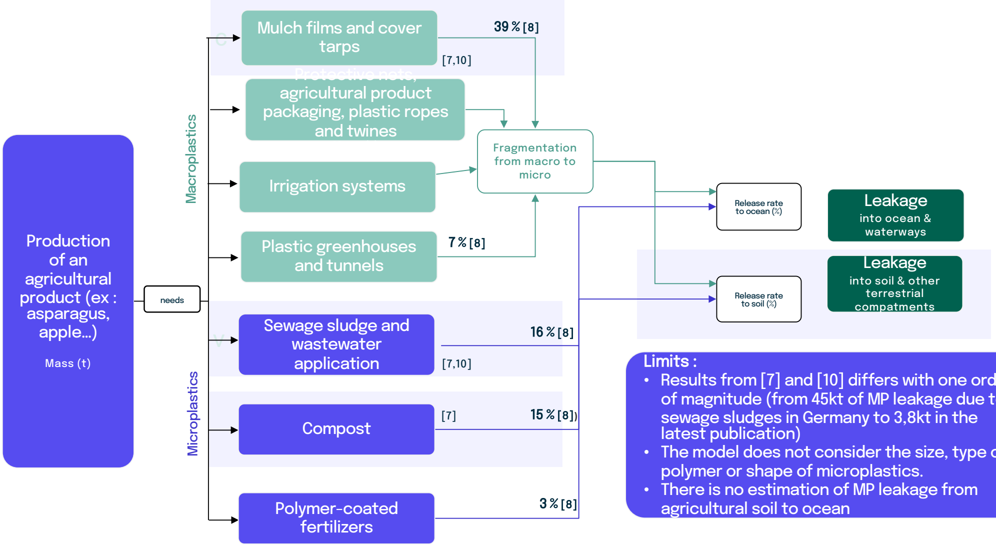
Crop categories are: asparagus, strawberries, cucurbits (including cucumbers, summer squash, and winter squash), lettuce, and early potatoes.

Could be used as follows :
- Establish secondary data by geographical region on the **area of agricultural soils**
- Establish secondary data by geographical region on the **distribution of crop categories**

- Establish secondary data on **the fraction of the area where mulch film or cover tarp is used per crop category**
- Establish secondary data on **loss factors**
- Establish secondary data on **thickness of foil per crop category**

System map for microplastic in agriculture

The path of microplastic leaks for producing an agricultural product - state of the art. The greyed areas indicate what the studies reviewed by PFN cover.



Limits :

- Results from [7] and [10] differs with one order of magnitude (from 45kt of MP leakage due to sewage sludges in Germany to 3,8kt in the latest publication)
- The model does not consider the size, type of polymer or shape of microplastics.
- There is no estimation of MP leakage from agricultural soil to ocean

[Attempt of] Meta analysis on plastic contamination in soils

Article	Analyse des sources d'émissions	Analyse des impacts	Quantification des contamination	Type de quantification (mesure, estimation)	Zone géographique	Culture	Pratique	Représentativité
[7]	/	/	OUI	Estimation en combinant des données de la littérature et des statistiques nationales et régionales sur les pratiques agricoles et les zones de culture (pour toute l'Allemagne)	Allemagne	Tous les sols agricoles	Boues de STEP, composts et palsticulture	Moyenne, extrapolation à partir de données nationales
[11]	/	/	OUI (revue de 23 études)	Mesure (méthodes d'extraction chimiques)	Chine, Chili, Canada, Allemagne, Australie, Mexique, Suède, Iran, Espagne, Danemark, USA	Sols agricoles, sols horticoles, prairies, vergers, forêts, champs en jachère (pour différents environnements : rural, urbain, site industriel)	Surtout boues de STEP, mais aussi films plastiques, serres plastiques, eaux usées	Très inhomogène, parfois un site ponctuel a été étudié, parfois plusieurs, la profondeur de sol étudiée varie de 3 cm à 50 cm
[9]	/	/	OUI (sur une période 1850 - 2022)	Mesure (méthode d'extraction chimique H2O2 et comptage par microscopie à fluorescence)	UK	Sols agricoles expérimentaux	Fertilisant inorganique, fumier organique, pas d'amendements	Très faible, sols expérimentaux avec pratique unique, seul objectif différencier les pratiques entre elles
[1]	OUI (50% de la masse des plastiques agricoles = films de paillage)	OUI	/	/	Monde	Agriculture végétale	Toutes	Globale
[13]	OUI (analyse des flux de plastique pour l'agriculture Suisse)	OUI (revue des organismes terrestres impactés)	OUI (tableau 2)	Estimations basées sur des enquêtes	Suisse	Sols agricoles	Nombreuses (pas de boues de STEP en Suisse)	Moyenne (données issues "d'enquêtes d'experts")
[12]	/	/	OUI	Estimation (MFA basé des mesures d'une précédente étude)	Suisse	Sols agricoles, horticoles et privés	Déchets organiques	Bonne mais spécifique à la Suisse
[10]	/	/	OUI (tableau 2)	Estimation statistique à partir de 442 échantillons de 43 articles (dont 372 pour la Chine)	Monde (mais surtout Chine)	Sols agricoles	Boues de STEP, films de paillage	Moyenne, statistiques faussés par le surepprésentation de la Chine
[15]	/	/	OUI (tableau 2)	Mesure de la teneur en MPs dans les boues de STEP dans une STEP au Royaume-Uni combinée aux résultats de 5 autres études et utilisation de données de la Commission EU et Eurostats pour l'utilisation des boues dans les pays européens	Europe	Sols agricoles	Boues de STEP	Bonne, se base sur une méthode de calcul, et sur les données de plusieurs études pour obtenir des données chiffrées pour les pays européens
[16]	/	/	OUI (figure 1)	Estimation à partir de 3 études sur les sources de MP et des données nationales	Europe	Sols agricoles	Boues de STEP	Faible, commence à dater, peut être confronté aux données de Lofty
	OUI (liste des différentes sources de plastiques contaminant les sols)	OUI (mécanismes de dégradation et listes des impacts : propriétés du sol, disponibilité de l'eau, polluants associés et leur toxicité, interactions avec le biote)	/	/	Monde	Sols en général	Toutes	Globale
[8]	OUI (les deux sources principales semblent être le paillages et les boues de STEP)	/	OUI (tableau 1)	Revue d'études qui ont fait des mesures	Hongrie, Chine, Japon, Thaïlande, Inde, Corée, Suisse, Allemagne, Grèce, Espagne, Pays-Bas, Tanzanie, Maurice, Tunisie, Chilie, Canada, Mexique	Sols agricoles en général	Films de apillage, boues de STEP, fertilisants enrobés, compost, serres, mix	Beaucoup de données inhomogènes, certaines pratiques pour seulement ou géographie, données en particules/kg de sol ou en mg de plastique par kg de sol
[18]	N/A	OUI	N/A	N/A	N/A	N/A	N/A	N/A
[19]	N/A	OUI	N/A	N/A	N/A	N/A	N/A	N/A

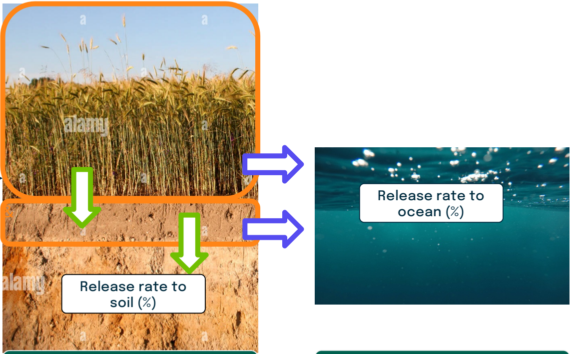
Calculation route and secondary dataset

Reference flux : 1 kg of agricultural commodity

X ha of land with the corresponding land use

X kg of macroplastics

X kg of macro & microplastics



Leakage
into soil & other terrestrial compatments

Leakage
into ocean & waterways

STEP 1 : Inventories to be established at commodity/landuse type scale and/or at country scale

STEP 2 : Release rates

Reduction of plastic release allowed by practice changes (quality of agricultural inputs, macro plastics management) may be addressed in a second phase

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Conclusions and perspectives

1. Sewage sludges, compost and plastic covers appear to be the main 3 source of MP leakage to soils [8]
2. There is one publication presenting models to estimation MP leakage to soil from sewage sludges, compost and plastic covers, but this model do not include size, type of polymer or shape of microplastics [7]
3. Estimation of soil PM contamination based on these models remains uncertain [10]
4. MP behavior in soil remains relatively unknown in term of temporal [9] and spatial [10] dynamics
5. No data was found to estimate MP leakage from agricultural to ocean
6. There is more and more measure of PM soil contamination but the diversity of measure techniques, level of detail and the representativeness of measurements sites limit the ability to perform meta-analysis [11]

Proposal for 2025 objectives

1. Investigating publications using MFA to relate MP leakage sources to MP contamination in crop soils [11,12]
2. Applying existing models to a case study, see methodology developed in [13]. Include macro-plastic leakage?
3. Investigating soil MP contamination data availability at country / world scale by targeted interviews
4. Discussing (again) with the impact working group on how to deal with the impact of plastic leakage from agriculture to soils and oceans

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