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Soil water repellency of two disturbed soils contaminated with different agricultural microplastics tested under controlled laboratory conditions

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ABSTRACT

Soil water repellency (SWR) significantly affects plant growth, along with surface and subsurface hydrology, posing a challenge for agricultural productivity and environmental sustainability. Nowadays, the occurrence of microplastics (MP) in the environment, particularly from agricultural practices, raises concerns about MP impact on soil properties. Among them, SWR is affected by hydrophobicity of MP particles detected in soils. This study introduces a method and presents results of a screening test to assess the effects of MP on SWR, utilizing Water Drop Penetration Time (WDPT) analysis under controlled laboratory conditions in destructed soil samples. We compared SWR of two soil types differing in portion of sand, loam and clay. Soils were mixed with three different types of MP originating from agricultural mulch films: low-density polyethylene (LDPE), biodegradable polybutylene adipate terephthalate (PBAT), and starch-based biodegradable plastics (Starch). The MP were milled to a uniform size range of some 10 to 300 µm and mixed with the soil samples. WDPT measurements were taken immediately after mixing and recorded for up to 60 s in order to find MP concentration levels at which strongly or more severely water repellency is inducted on soil samples. Our findings reveal that both, soil type and MP type significantly influence SWR, where there are notable differences observed between bio-based (Starch based) and non-bio-based (LDPE and PBAT) plastics' effects on SWR in the two tested soil types. Data highlights the distinct behaviour of Starch in altering soil hydrophobicity, prominently different from the impact of both PBAT and LDPE. The measurement technique we have developed for quantifying SWR levels could be used for both research applications and the dissemination of findings. It can significantly enhance decision-making processes regarding the selection of optimal plastic alternatives for agricultural use.

1. Introduction

Plastic pollution is an emerging global threat to ecosystems (de Souza Machado et al., 2018a; Barnes et al.2009). Despite the fact, that soils are the largest sink of microplastics (MP) (diameter < 5 mm), terrestrial ecosystems have received far less scientific attention compared to their aquatic counterparts (Nizzetto et al., 2016). For example, MP contamination on land might be 4–23-fold larger than in the ocean (Horton et al., 2017). Plastics are poorly degradable by nature leading to their accumulation in the environment. Consequently, biodegradable and bio-based materials are promoted as more sustainable alternatives to conventional plastics (Zimmermann et al., 2020; Lambert and Wagner, 2017). The largest input of plastic into the soil environment are mulch films, intensively used in agriculture (Li et al., 2022; Nizzetto et al., 2016). Initiatives are underway to create environmentally friendly alternatives and recycling methods for agricultural plastics, aiming to reduce their environmental footprint. This includes the exploration of bio-based and biodegradable plastics.

Polyethylene (PE) has become by far the most frequently used polymer in agricultural mulch production (Steinmetz et al. 2016). Low-density polyethylene (LDPE) dominates the mulching film market, because of its high puncture resistance, tensile strength, and resistance to exposure to solar radiation and low temperatures (Serrano-Ruiz et al., 2021). Impacts of mulching film pollution on soil properties have been observed decades ago leading to development of more environmentally friendly substitutes (Long et al., 2023). As a potential alternative to

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conventional non-degradable mulching films, a variety of different biodegradable mulching films are already available on the market (Merino and Alvarez, 2019). The most used fossil-based biodegradable plastic for mulch films in Europe is polybutylene adipate terephthalate (PBAT) (Manger; European Bioplastics, 2022). PBAT has high elasticity, wear, and fracture resistance, as well as resistance to water and oil. This material is biodegradable in soil and compostable, certified according to relevant European standard specification (EN 17033, 2018), but its degradation in soil is estimated as moderately low (Sintim et al., 2020). To increase degradation of mulch films in soil (Serrano-Ruiz et al., 2021) starch-based materials are used. Starch is an abundant polymer coming from renewable sources (Mitrus, 2010) and so far, it represents a large share of the current bio-based plastics used (Manger; European Bioplastics, 2022).

Plastics induce both physical and chemical transformations in the microenvironment, posing an environmental challenge, particularly with more persistent types of plastics (Cousins et al., 2019; de Souza Machado et al., 2018b). For example, once in soils, MP can combine with minerals and organic matter in soils and affect soil physical properties, such as bulk density, aggregate stability, water-holding capacity and soil water repellency (SWR) (Qi et al., 2022; de Souza Machado et al., 2018b). Botyanszká et al (2022) provided comparison among three types of MP contamination (high-density polyethylene – HDPE, polyvinyl chloride – PVC, and polystyrene – PS) and reported that all types of plastics significantly reduced the bulk density measured after the growing period (GP), while HDPE treatment increased hydraulic conductivity and water sorptivity. Botyanszká et al (2022) did not observe statistically significant changes in SWR and radish growth in the MP treatments at the end of growing period. In addition, Qiang et al (2023) and Smettem et al (2021) provide extensive report on effects of polyethylene MP presence on induction of SWR, reduction of capillary flow and influence on soil biota ingestion and transport of MP in the agroecosystems.

SWR, also known as hydrophobicity, has been ranked as one of the major soil constraints to successful agriculture (Doerr et al., 2000; Dekker and Ritsema, 1994). SWR can, along with other stressors effect on plants resulting in poorer yield quality (Smettem et al., 2021; Ruthrof et al., 2019; Hallett, 2007). SWR is created by the amount, nature and configuration of soil organic material (Doerr et al., 2000; Seaton et al., 2019; Mao et al., 2018;), i.e. results from waxy organic compounds coating soil particles (González-Peñaloza et al., 2013). Sandy soils (< 5 % clay) are most susceptible to water repellency while on the other hand, clay can help to alleviate water repellency (Shafea et al., 2023; Guo et al., 2022). In addition, the level of repellency is influenced also by the specific surface area of the soil, which varies considerably with soil texture (Leelamanie et al., 2010). Again, sandy soils have the lowest surface area, so a hydrophobic surface will impact a larger proportion of particles than for a loamy or clayey soil where the surface area is up to three orders of magnitude greater (Woche et al. 2005). While the phenomena of SWR and its causes and consequences are well-established, the pollution of soils with MP raises novel inquiries.

It is known that the hydrophobic nature of plastics, when introduced to soil, disrupts soil water dynamics (Bodor et al., 2024). MP usually displays high hydrophobicity and unique structural properties (e.g., surface charge, density and shape) (Campanale et al., 2020; Zhang et al., 2020; Zhou et al., 2020). The hydrophobicity of MP (low wettability of surfaces) particles causes intense repulsion to water molecules and water availability in soil (Shafea et al., 2023; Guo et al., 2022; Kumar et al., 2020). The presence of MP tends to increase contact angle (i.e., water repellency) and saturated hydraulic conductivity, decrease bulk density and change water holding capacity. These changes depend on particle size and concentration (Yu et al., 2023; Wang et al., 2023). Various authors report significant alterations in SWR when MPs are either deposited on the soil surface or incorporated into the soil (Qi et al., 2020; Cramer et al., 2022).

A wide variety of tests and techniques have been developed to quantify SWR (Mao et al., 2018). The most widely used test for the persistence of SWR is the Water Drop Penetration Time (WDPT) test (Letey et al., 2000; Doerr 1998). The test is performed by placing droplets of water onto the surface of a soil sample and recording the time of their infiltration. The use of an arbitrary WDPT threshold is applied to differentiate between hydrophilic (wettable) and hydrophobic (water-repellent) soils (Dekker and Ritsema 1996). Most widely used WDPT threshold are presented in Table 1. The WDPT test is usually conducted in the field but could also be used in laboratory settings on disturbed soils (Hallett, 2007).

The study presents an adopted WDPT used under laboratory conditions on destructed soil. The applicability of this method was tested on two soils contaminated with three types of MP, i.e. LDPE, PBAT, and starch-based bioplastics, which represent conventional, biodegradable, and bio-based biodegradable plastics respectively. (1) We hypothesize that low wettability of MP induces soil water repellency, depending on MPs type and concertation. (2) We also hypothesize that soil water repellency induction differs between different soil types and different MP applied. Data on soil water repellency is an important parameter to be considered when different plastics are compared for their applicability in agriculture.

2. Materials and methods

2.1. Soils

We tested two soil types obtained at two different locations at 30 cm depth. Based on the USDA soil texture classification (Soil survey manual, 2024) the first soil type (T_1) **was silty-clay-loam soil**, obtained from the research field in central Slovenia (Ljubljana, 46°02′55.3″N; 14°28′18.5″E). It contained 20 % sand, 50 % silt and 30 % clay with 4.8 % organic matter. The second soil type (T_2) was **sandy-loam**, in proportion of 67 % sand, 22 % silt and 11 % clay with 1.7 % organic matter from the eastern part of Slovenia (Žadovinek, 45°56′33.7″N; 15°30′00.2″E). Soil samples collected from the fields were owen-dried at 40 °C for 24 h and sieved trough 500 μm mesh. The sieving was performed in order to achieve a more uniform particle size distribution to reduce variability in our experimental conditions, which could have significantly influenced the accuracy of our measurements. After drying, the samples were stored in sealed containers until the MP mixtures were prepared. Although González-Peñaloza et al. (2013) report on effects of sample drying on WDPT, our primary goal was to ensure that the soil samples were completely dry before mixing with MP. Because the sieving step might have led to a significant reduction in the coarser sand fraction, impacting the overall texture of the samples, we analysed the soil texture both before and after the sieving process. The granulometric distribution data indicates that, in the T_1 sample, the sand fraction decreased from 20 % before sieving to 10.2 % after sieving. The loam and clay fractions adjusted correspondingly. For T_1, silt fraction increased from 50 % to 56.8 % and clay fraction from 30 % to 33 % after sieving. Regardless this fraction changes, the overall soil texture classification remained unchanged as **silty- clay- loam soil type**. In the T_2 sample, the sand fraction decreased from 67 % to 34.5 %, the silt fraction increased from 22 % to 43.4 % and clay fraction from 11 % to 22.1 %, after sieving. These changes indicate a shift in the texture type for the T_2 soil used, **from sandy-loam to loam soil**, based on the USDA soil texture classification (Soil survey manual, 2024).

2.2. Microplastics tested

We tested LDPE, PBAT, and Starch MP. MP particles were milled from commercially available LDPE, PBAT and Starch mulch films. LDPE had a density of 0.93 g/cm^3, PBAT 1.45 g/cm^3 and Starch 1.28 g/cm^3.

2.3. Scanning electron microscopy of plastic samples

The morphology, estimation of size distribution and shape of LDPE, PBAT and Starch mulch MP was inspected by scanning electron microscopy (SEM). The milled material was placed on carbon discs mounted on aluminium holders and sputter-coated with gold/palladium (8 nm) using precision etching coating system (Gatan 682, Pleasanton, CA, USA). Particles were examined with a field emission scanning electron microscope (SEM, JEOL JSM-6500F, Tokyo, Japan).

2.4. Measurements of soil water repellency

We tested 2 types of soils mixed with MP in a range of MP concentrations (details are provided in Appendix A). Each mixture of soil and MP was manually stirred in a metal container using a procedure to ensure consistency across all samples. The mixing was as follows: stirring the mixture 10 times clockwise, followed by 10 stirs counter clockwise, 10 crosswise stirs from left to right and finally, mixing back and forth within the container 10 times.

After achieving a homogeneous mixture, the sample was divided into five equal portions using a measuring spoon to get a small heap. These small heaps (height 3 cm) were compacted under 50 g weight to get flat upper surface for water droplet penetration tests. Three drops of distilled water from a pipette were placed on the flat surface of the soil sample and the time taken for the drops to infiltrate into the soil was measured (Dekker and Ritsema 1994). For details about the method see Appendix A. Based on the repellency classes presented in Table 1, we categorized WDPT times of samples into four adopted categories based on WDPT: (1) Wettable (WDPT < 5 s); (2) Slightly water repellent (WDPT 5–30 s); (3) Moderately water repellent (WDPT 30–60 s) and (4) Strongly or more water repellent (WDPT > 60 s) (Doerr et al., 2007; Dekker and Ritsema, 2000; Dekker and Ritsema 1994*)*. Categories chosen helped us find the transition MP concertation levels between wettable and slightly water repellent and slightly to strongly or more repellent samples. The lower boundary of transition zone was identified as the minimal MP concentration at which at least one sample exhibits slight water repellency (WDPT between 5 s and 60 s). Conversely, the upper boundary of transition zone is determined by the maximum MP concentration at which we still observe at least one sample not classified as strongly water repellent (WDPT > 60 s). Our maximal recording time was set to 60 s, as our aim was not in finding the transition between strongly (WDPT 60–600 s) and severely (WDPT 600–3600 s) or between severely (WDPT 600–3600 s) and extremely (WDPT > 3600 s) water repellence induction of MP in soil. Using adopted categorization levels also helped us with time optimization of the laboratory test and enabled us to test more concentrations in order to more accurately find transition MP concentration levels of interest. The concentrations of MP tested in this study do not necessarily reflect actual environmental levels but rather provide a theoretical understanding of how MP concentration influences SWR, but some high MP concentrations can be found in soils that are heavily contaminated, such as those found in urban environments (Büks and Kaupenjohann, 2020; Nizzetto et al. 2016). These controlled conditions allow us to explore the relationship between increasing MP concentration and changes in soil behaviour, marking the shift from WDPT wettable to slightly and slightly to strongly repellent categories after adding all three types of MP to soil. Tests were performed under laboratory conditions, with 24 °C room temperature and 68 % of relative air humidity during the measurements.

Table 1
Most used WDPT thresholds and

Water repellency class	Doerr et al.	Bisdom et al.	Adams et.al
	Water drop penetration time		
Wettable	< 5 s	< 5 s	< 10 s
Slightly water repellent	10, 30, 60	5–60	10–60
Strongly water repellent	180, 300, 600	60–600	
Severely water repellent	900, 1800, 3600	60–3600	> 60
Extremely water repellent	> 3600	> 3600	

adopted from Doerr et. al. (1998), Bisdom et al., (1993)Adams et al., (1970).

2.5. Statistical analysis

Statistical analyses of WDPT data were performed using R statistical software (version 4.2.1) and IBM SPSS software (version 25.0). Relative frequencies in each WDPT category for different MP concentration levels were presented using stacked bar plot. The results are detailed further in Appendix B.

When assumptions for Pearson Chi Squared test were not met (expected frequency was less than 5 for more than 20 % cells), the Fisher exact test was utilized to evaluate the differences in WDPT across six treatment groups, which were differentiated by soil types and MP categories, at each MP concentration level. We established statistical significance at the alpha (α) level of 0.05. This threshold was used to determine the significant differences in WDPT values between the treatment groups and MP concentrations.

3. Results

3.1. Microplastics tested

The milling process generated a very broad size distribution of particles ranging from less than 10 µm (in case of LDPE) to up to 400 µm (Fig. 1A, B and C). Particles are of irregular shape in all three cases. In all materials particles showed evidence of stretching, tearing and crushing rather than 'clean' fragmentation. High aspect ratio particles (e.g. fibers) were found in all cases (Kühn et al., 2018). There are no significant differences in surface morphology and shape among the three different types of MP.

3.2. Water drop penetration time test

The results on WDPT presented in Fig. 2 illustrate the distribution of WDPT across two distinct soil types, each mixed with three different MP types. Each data point within the stacked bars represents an aggregate of N = 15 samples (each of the 5 heaps had 3 droplets of water, 1 droplet represents one measurement) for each concentration measured. For control soils, i.e. 0 % MP, the soils are considered wettable, indicated by WDPT values less than 5 s, in both soils. With higher concentration of MP in soil, WDPT times increase. We analysed a range of MP concentrations in a way to identify concentration of MP with WDPT values less than 5 s (WDPT < 5 s), i.e. wettable soil, WDPT values 5–60 s, i.e. slightly water-repellent soils and equal or more than 60 s (WDPT > 60 s), i.e. repellent soil.

In Fig. 2, the transition zone between wettable and strongly or more repellent is highlighted using black rectangles. In this way differences among samples could be clearly identified. The lower boundary of transition zone is identified as the minimal MP concentration at which at least one sample exhibits slight water repellency (WDPT between 5 s and 60 s). Conversely, the upper boundary of transition zone is determined by the maximum MP concentration at which we still observe at least one sample not classified as strongly water repellent (WDPT > 60 s). This approach enables to delineate the critical concentration window within which the soil's water repellency begins to increase significantly.

The identified transition concentration levels, marking the shift from wettable to significantly water-repellent soil conditions after adding all three types of MP to soil. However, the plastics differ in their potential to provoke this shift.

Specifically, for silty clay loam soils (soil T_1) mixed with conventional LDPE, the transition concentration levels are observed between 1.0 % and 1.3 % MP content. While loam soils (soil T_2) with LDPE exhibit transition concentration levels at lower MP contents, ranging from 0.6 % to 1.0 %.

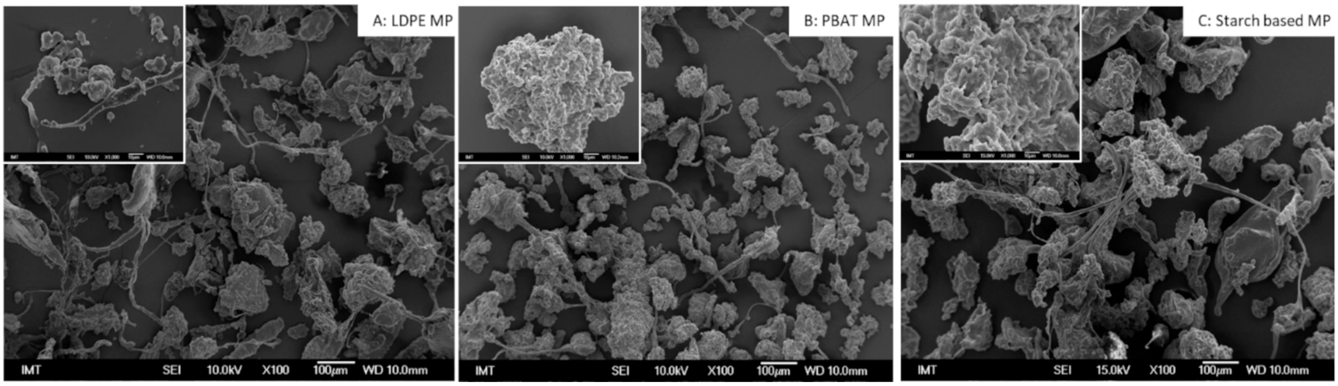

Fig. 1. Scanning electron microscopy images of MPs from LDPE (A), PBAT (B) and starch-based films (C).

Fig. 2. Relative frequencies of WDPT times for N = 15 samples (measurements) at each concertation level for six treatments. Differences between starch and PBAT / LDPE water repellency induction are visible in black rectangle which indicated the transition zone concentration levels between wettable (WDPT < 5 s) and strongly or more repellent (WDPT > 60 s) samples. At higher MP concentration levels (higher than 3 % of MP), only starch treatment shows lower induction of water repellency in samples for both soil types (i.e. silty clay loam and loam).

When comparing soils mixed with PBAT, a biodegradable plastic, the transition concentration levels are similar to those of LDPE between 1 % and 1.5 % of MP content. However, loam soils show a much narrower and lower transition range when combined with PBAT, cantered around

0.8 %[1] MP content.

The transition concentration levels of MP, indicating the shift from wettable to slightly water repellent and from slightly to strongly water-repellent soil samples, are substantially higher for Starch-bioplastics compared to those for both PBAT (biodegradable plastics) and LDPE (conventional plastics), across all soil types. The concentration levels required for Starch to induce changes in soil water repellency—-transitioning from slightly repellent (at the initial transition of approximately 4 % MP in soil) to strongly repellent (at the secondary transition seen in Fig. 2 of approximately 25–30 % MP in soil)—are notably higher than those observed for PBAT and LDPE (first and second transition concertation levels lower than for starch). Also, we have observed some differences between two soil types that have been mixed with the same MP type. The transition concentration levels between slightly and strongly water repellent for silty clay loam of 1.5 % of PBAT has been observed, while for loam soil 0.8 % of PBAT has been observed. This means that Starch-bioplastics has lower potential to cause soil water repellency. This data, visualized in Fig. 2 and detailed in Table 2, highlights the distinct behaviour of Starch in altering soil hydrophobicity, prominently different from the impact of both PBAT and LDPE. The transition levels estimation errors are added based on the density of MP concentration level measurements near the lower and upper transition zone (i.e. Starch upper transition level for loam has higher estimation error, as LDPE / PBAT for loam soil type).

Appendix B presents the results of the Fisher statistical test, applied to compare WDPT across six treatments at varying MP concentration levels. The analysis reveals statistically significant differences in WDPT values for all MP concentrations exceeding 0.8 % (the initial transition threshold for loam soil mixed with PBAT), with p-values less than 0.05 indicating strong statistical significance. This trend of significance persists across most of the MP concentrations tested, with one notable exception, the 32 % MP concentration level. At this concentration, the WDPT exceeded 60 s for all samples, regardless of the treatment applied.

4. Discussion

SWR is among the most important properties of soil. Its main effect, limiting water infiltration, not only impacts plant growth but can also potentially lead to soil erosion (Mao et al., 2018; Mao et al., 2016). In the study reported here, we provide evidence that low wettability (high hydrophobicity) of MP induces SWR, depending on soil, MP and types and shape. The shape of plastic particles plays a crucial role in assessing their environmental impacts (Shi et al., 2022), and our results using scanning electron microscopy (SEM) to compare particle morphology, support this finding. In line with literature data, also our laboratory study confirms that the WDPT was higher for all the treatments with plastic particles as compared to the control (Qi et al 2020). In addition, we adopted a WDPT measurements to be used under highly controlled laboratory conditions. Such test allows comparison among different plastic particles and soils to supplement other measurements either in the laboratory or under more realistic field conditions.

Table 2
Transition concentration levels between wettable (< 5 s) and strongly water-repellent samples (> 60 s).

Soil type	Microplastics type	Lower transition concentration level (%)	Upper transition concentration level (%)
Sandy clay loam	LDPE (conv.)	1.0 ± 0,2	1.3 ± 0,1
	PBAT (bio)	1.0 ± 0,2	1.5 ± 0,1
	Starch	4.0 ± 1.0	31.0 ± 1.0
Loam	LDPE (conv.)	0.6 ± 0.2	1.0 ± 0.2
	PBAT (bio)	0.8 ± 0.2	0.8 ± 0.2
	Starch	4.0 ± 1.0	25–30

We confirmed that loam soil type is more water repellent at lower MP concentrations than silty clay-loam-soil after contamination of any of the three tested MPs (LDPE, PBAT and starch MPs). However, differences of MP induction between the two soil types are not very pronounced. Our results are aligned with literature data reporting soil texture as an important factor controlling SWR levels. A large body of research shows the implication of soil texture i.e. the proportion of sand, silt and clay sized particles (the mineral fraction of the soil) are related to SWR levels. Although SWR can occur in a wide range of soil textures, sandy soils are susceptible to coating by hydrophobic materials because of their low surface area (SA) (Bayad et al., 2020). In addition, coarse-textured soils have a lower specific surface than fine-textured soils, and a limited amount of organic matter may cause higher SWR than in finely textured soils (González-Peñaloza et al., 2013). As the mechanism of SWR is very complex depending on many other factors it is difficult to draw a solid conclusion on the impact of soil texture and SA on the potential SWR. For further analysis and new conclusions, more different soil types should be studied, to see if other soil types also have similar WDPT times at similar MP concentrations.

As well, longer WDPT times should be measured e.g. between strongly (60–600) and severly (600–3600). Despite that, the laboratory test we have adopted is sensitive enough to discriminate between the two soil types based on the SWR. In our study we have used sieved soil (500 μm mesh) before mixing it with plastics particles to reduce the effect of soil structural aggregates size on the measured parameters.

SWR could be assessed in field or under laboratory conditions (Ritsema and Dekker 1994; Dekker and Ritsema, 1994; King 1981). As SWR is a measure of how long it takes to break down the repellent property after prolonged contact with water to make the soil wettable again, the most direct measurement is via water droplet penetration time. Our method is based on analyses of oven-dried and sieved soil (500 μm mesh) mixed with known amount of MP particles just before the analyses. The aim of the tests is to assess how different plastic particles added to dry soil change soil water droplet penetration time. We set a transition zone between wettable (WDPT < 5 s) and strongly or more repellent (WDPT > 60 s) based on the duration of water droplet to penetrate the sample. Based on preliminary testing we set 60 sec as the maximum recording period for water droplets to penetrate the soil sample. We were particularly interested in the limit or concentration where the transition from wettable to slightly water repellent and from moderately to strongly is reached. These transitions are crucial in an environment where plastic pollution is increasing. With the global production of 400 million tons of plastic in 2022 (Wang et al., 2023) it has been clearly documented that plastic and plastic debris are present terrestrial environments while being an emerging threat to ecosystem functions, with SWR as no exception (Dissanayake et al., 2022; Guo et al., 2022). With defining 60 s as the maximum recording period, we optimized the time of measurements for higher number of samples. By defining the transition zone window one can compare various soil types mixed with MP. As research suggests there are general thresholds for SWR based on WDPT. The specific threshold at which SWR begins to negatively affect plant growth can vary but typically starts when WDPT exceeds 5 s (Bayad et al., 2020; Siteur et al., 2016). In highly affected soils, such as those contaminated with MP or other hydrophobic substances, the impact on plant growth can be even more pronounced, especially when SWR severely restricts water movement (Bayad et al., 2020). This is why, we must make sure to measure WDPT times at MP concertation levels that are sufficient to detected transition zone MP concentration levels with enough accuracy. The concentration levels of MP vary depending on both the type of soil and the plastic material. Fig. 2 illustrates this in detail, with the transition zones clearly marked

[1] At 1 % of PBAT MP, higher than 60s WDPT time has been measured for all 15 samples and for 0.6 % PBAT MP lower than 5s WDPT time has been measured for all 15 samples.

by black rectangles, highlighting areas of induction. This is achieved with higher density of MP concentration measurements, near the upper and lower transition levels. All details about the protocol are in Appendix A.

5. Conclusions

The data obtained with this study illustrates significant differences between bio-based versus no-bio based plastics on SWR in two tested soil types. Furthermore, the study highlights the importance of using scanning electron microscopy (SEM) to compare particle morphology.

Presented findings demonstrate that LDPE plastics result in higher WDPT than starch-based MP at equivalent concentrations. In our study, conducted under controlled conditions, we confirmed that starch-based plastics are less detrimental to SWR than LDPE and PBAT plastics, providing theoretical insight into the relationship between MP concentration and SWR. Since petroleum-derived plastics have been studied more extensively than bio-based alternatives, our findings contribute to addressing this knowledge gap. SWR significantly affects water infiltration and movement. The accumulation of MP in soil, a consequence of plastic use in agriculture, is expected to exacerbate SWR in the future. Given the altered soil conditions caused by MP, it will be necessary to adapt agricultural practices and broader farming systems accordingly.

We conclude that the less detrimental effect of starch-based plastic should be pointed in order to contribute to research of new agricultural materials. This research advances the limited understanding of the environmental impact of bio-based plastics, addressing a critical gap in the current literature. A key contribution of this work lies in the development of an adapted research methods for further research on different MP effect on SWR. This underscores the importance of exploring bio-based alternatives but also innovating and improving research techniques to effectively reduce the reliance on non-biodegradable plastics in agriculture, thereby mitigating their environmental footprint.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.geoderma.2024.117124.

Data availability

Data will be made available on request.

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