Ref. Ares(2025)6377295 - 05/08/2025

MINAGRIS

Deliverable 5.1

Effects of MNP on the soil physical properties related to soil water

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101000407 (MINAGRIS). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Document Control Information

Settings	Value
Deliverable Title	Effects of MNP on the soil physical properties related to soil water.
Work Package Title	WP5: Assessment of the impact of MNP and combined effects with other stressors on soil physical and chemical properties and crop productivity
Deliverable number	5.1
Description	Report
Lead Beneficiary	University of Ljubljana (UL)
Lead Authors	Železnikar Špela
Contributors	Noč Matic, Žvokelj Luka, Pirnat Matjaž, Angelica Barone, Marta Bertola, Pintar Marina
Submitted by	Esperanza Huerta Lwanga
Doc. Version (Revision number)	2
Sensitivity (Security):	Public
Date:	31/07/2025

Document Approver(s) and Reviewer(s):

NOTE: All Approvers are required. Records of each approver must be maintained. All Reviewers in the list are considered required unless explicitly listed as Optional.

Name	Role	Action	Date
Esperanza Huerta Lwanga	Co-coordinator	Review	16 July 2025

Document history:

The Document Author is authorized to make the following types of changes to the document without requiring that the document be re-approved:

- Editorial, formatting, and spelling
- Clarification

Configuration Management: Document Location

The latest version of this controlled document is stored in <location>.

Nature of the deliverable		
R	Report	x
DEC	Websites, patents, filing, etc.	
DEM	Demonstrator	
O	Other	

Dissemination level		
PU	Public	x
CO	Confidential, only for members of the consortium (including the Commission Services)	

ACKNOWLEDGEMENT

This report forms part of the deliverables from the MINAGRIS project which has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101000407. The Consortium is not responsible for any use that might be made of the content of this publication.

MINAGRIS - MIcro- and NAno-Plastics in AGRIricultural Soils: sources, environmental fate and impacts on ecosystem services and overall sustainability– is an H2020 project funded under the H2020 Programme, coordinated by WAGENINGEN UNIVERSITY (WU).

The MINAGRIS project, launched on September 1st, 2021, aims to contribute to healthy soils in Europe by providing a deeper understanding and tools to assess the impact of MP and NP in agricultural soil health. To create an overview on the actual situation across Europe, MINAGRIS will assess the use of different plastic polymers in agricultural systems in 11 case studies across Europe and identify the resulting types and concentrations of MPs and NPs. Concentrations of other stressors in soils such as pesticides and veterinary drugs will be additionally assessed. MINAGRIS will provide validated analytical tools that allow the quantification and identification of MPs and NPs in European agricultural soils.

The project, funded by the EU Research and Innovation Programme Horizon 2020 under Grant Agreement n. 101000407, gathers 20 partnering organisations from 12 EU Member States countries with various biogeographical regions and representative of different farming systems and soils across Europe. It has an overall budget of approximately €7 million and will run for 5 years, between September 2021 and September 2026.

More information on the project can be found at: https://www.minagris.eu

TABLE OF CONTENTS

1. INTRODUCTION 1

2. EXPERIMENTAL SITES 2

2.1 WAGENINGEN EXPERIMENTAL SITE 2
2.2 DIJON EXPERIMENTAL SITE 3
2.3 CRETE EXPERIMENTAL SITE 3
2.4 FIELD SITES SOIL PROPERTIES 4

3. ANALYSIS OF SOIL PHYSICAL PROPERTIES 5

2.1 SOIL BULK DENSITY 7
2.2 SATURATED HYDRAULIC CONDUCTIVITY 7
2.2.1 Determination of Saturated Hydraulic Conductivity (Ks) 7
2.3 SOIL WATER RETENTION 8
2.3.1 Hyprop 8
2.3.2 Pressure Plate Extractor Method for Wilting Point Determination 9
2.4 SOIL AGGREGATE STABILITY 9
2.5 DATA ANALYSIS 5

3. MICROPLASTIC EFFECT ON SOIL PHYSICAL PROPERTIES 9

3.1 SOIL BULK DENSITY 10
3.2 HYDRAULIC CONDUCTIVITY 12
3.3 SOIL WATER RETENTION 14
3.4 SOIL AGGREGATE STABILITY 16

4. GENERAL CONCLUSIONS 18

5. LIST OF REFERENCES 20

LIST OF ABBREVIATIONS

CEC	Cation exchange capacity
CL	Clay-loam soil type
Cv	Coefficients of variation
ISO	International Organization for Standardization.
Ks	Saturated Hydraulic Conductivity
LDPE	Low density polyethylene;
LS	Loamy-sand soil type
mmol	Thousandth of a mole
MNP	Micro- nano plastic
MP	Microplastics
MWD	Mean weight diameter of water-stable aggregates
PBAT	Polybutylene adipate terephthalate
pF	Potential force, describes the effort it takes the plants' roots to extract water from the soil
SCL	Sandy-clay-loam (soil type)
SD	Standard deviation
SE	Standard error
WP	Wilting point

EXECUTIVE SUMMARY

The increasing use of plastic materials in agriculture—especially plastic mulch films—has led to growing concerns about the accumulation of microplastics (MP) and nanoplastics (NP) in agricultural soils. These particles may alter crucial soil physical properties, impair soil water dynamics, and negatively impact crop performance and long-term soil health. In response to these concerns, the MINAGRIS project assesses the environmental risks of micro- and nanoplastics (MNP) in soil, with a specific focus on their influence on soil water-related physical properties.

This deliverable summarizes findings from field experiments conducted at three experimental sites representing European pedoclimatic zones: Wageningen (Netherlands – Atlantic), Dijon (France – Continental), and Crete (Greece – Mediterranean). These sites are managed by national research teams within the MINAGRIS consortium and serve as testbeds for assessing the impacts of MNPs on key soil functions.

Deliverable 5.1 evaluates how MP—including conventional plastics (LDPE), biodegradable types (PBAT), and biobased alternatives (starch-based MP)—affect soil physical properties such as: soil bulk density, saturated hydraulic conductivity, soil water retention and aggregate stability. Additionally, the interactions between MPs and veterinary pharmaceuticals (e.g., albendazole) were explored to reflect real-world conditions in agriculture.

Initial results reveal that the effects of MP on soil physical properties are variable and context-dependent, influenced by soil type, climate, and plastic type. While some treatments showed minor changes in water retention or conductivity, no consistent detrimental impact was observed across all locations. The findings underscore the importance of site-specific evaluations and highlight the need for further research to understand long-term effects, especially under field conditions. Statistical analysis will be conducted after the two-year experiment to ensure more robust and reliable comparisons. This approach accounts for inter-annual variability, increases statistical power, and minimizes the influence of seasonal anomalies. It also enables direct comparisons across years, helping to assess the consistency of treatment effects over time.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101000407 (MINAGRIS). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

1. INTRODUCTION

The widespread use of plastic products in agriculture, particularly plastic mulch films, has raised increasing concern over the accumulation of microplastic (MP) particles in soils. These particles have the potential to alter key soil physical properties, disrupt ecosystem functioning, and ultimately reduce agricultural productivity. Consequently, there is a growing interest in identifying sustainable alternatives to conventional plastics in agricultural systems.

Plastic materials are extensively used across multiple sectors worldwide due to their durability, ease of handling, and cost-effectiveness (Dissanayake et al., 2022; Železnikar et al., 2025a). In 2022, global plastic production reached approximately 400 million tons (*Plastics Europe • Enabling a Sustainable Future*, n.d.; Wang et al., 2023) contributing to the pervasive presence of plastic debris in both terrestrial and aquatic environments (Babaei et al., 2024; Dissanayake et al., 2022; Walenna et al., 2024).

Microplastics are introduced into the environment through two primary pathways. Primary microplastics are intentionally manufactured small particles used in products such as personal care items and industrial abrasives. Secondary microplastics, on the other hand, result from the degradation of larger plastic items through physical, chemical, or biological processes (Železnikar et al., 2025a; Santis et al., 2024; Z. Wang et al., 2023).

In agricultural soils, MPs originate from several key sources, including the application of plastic mulches, sewage irrigation, and the use of sewage sludge as fertilizer (Gao et al., 2020). Additional inputs include landfill leachate seepage (Hoang et al., 2024; Silva et al., 2021), municipal compost contaminated with plastic residues and atmospheric deposition (Fan et al., 2022; Hu et al., 2021; Nourozi et al., 2024).

Once MP particles enter the soil environment, they can readily disperse through the soil matrix, driven by a variety of natural and anthropogenic processes. Wet–dry cycles (Jin et al., 2022; W. Wang et al., 2020), bioturbation by soil organisms (Meng et al., 2024), routine soil management, and harvesting activities all contribute to the redistribution of MPs within the soil profile. Additionally, soil type plays a significant role in the movement and retention of MPs. According to Wang et al.(2022), sandy soils—with their large pore spaces—facilitate greater MP mobility, enabling deeper and broader distribution than clay soils. Soils with high clay or loam content tend to restrict vertical movement due to smaller pore sizes, resulting in greater MP accumulation near the surface.

Once incorporated into the soil, microplastics can interact with mineral particles and organic matter, becoming integrated into the soil matrix. These interactions can alter key soil physical properties, including bulk density, aggregate stability, water-holding capacity, and water repellence (Hassan et al., 2022; Qi et al., 2020a). The specific physical and chemical characteristics of MPs—such as hydrophobicity, surface functionalization, surface charge, and particle size—are known to influence soil hydraulic behaviour (Gong & Xie, 2020; Hanif et al., 2024).

Recent investigations indicate that increasing MP concentrations in soil reduce the number of micropores and macropores, leading to a decline in soil hydraulic conductivity (Guo et al., 2022; Kumar et al., 2020). MPs can physically block soil pores, impeding the transport of water and nutrients to plant roots (Sajjad et al., 2022). Furthermore, the inherent hydrophobic nature of many MP particles contributes to water

repellency in soils (Železnikar et al., 2025a), potentially reducing soil water availability and affecting plant water uptake (Kumar et al., 2020).

2. EXPERIMENTAL SITES

The MINAGRIS project investigates the impacts of micro- and nanoplastics (MNPs) on soil physical properties across different European experimental sites. Field experiments are conducted at three long-term experimental platforms located in Wageningen (Netherlands), Dijon (France), and Crete (Greece), representing Atlantic, Continental, and Mediterranean regions, respectively. Each site is managed by local research partners (*MINAGRIS - Home*, n.d.).

At each site, used MP (*LDPE – Low-density polyethylene*; *PBAT-polybutylene adipate terephthalate and Starch-based MNP*) effects are studied under realistic agricultural conditions. Field plots follow a completely randomized design with five replicates per treatment. Treatments include a control and a single MNP dosage, both applied with and without a selected veterinary drug (Albendazole, anthelmintic) to assess combined effects on soil and crop systems.

2.1 WAGENINGEN EXPERIMENTAL SITE

The field experiment was conducted during the 2024 growing season at coordinates 51.9897°N, 5.6609°E (Figure 1). The site experienced natural climatic conditions without supplemental irrigation.

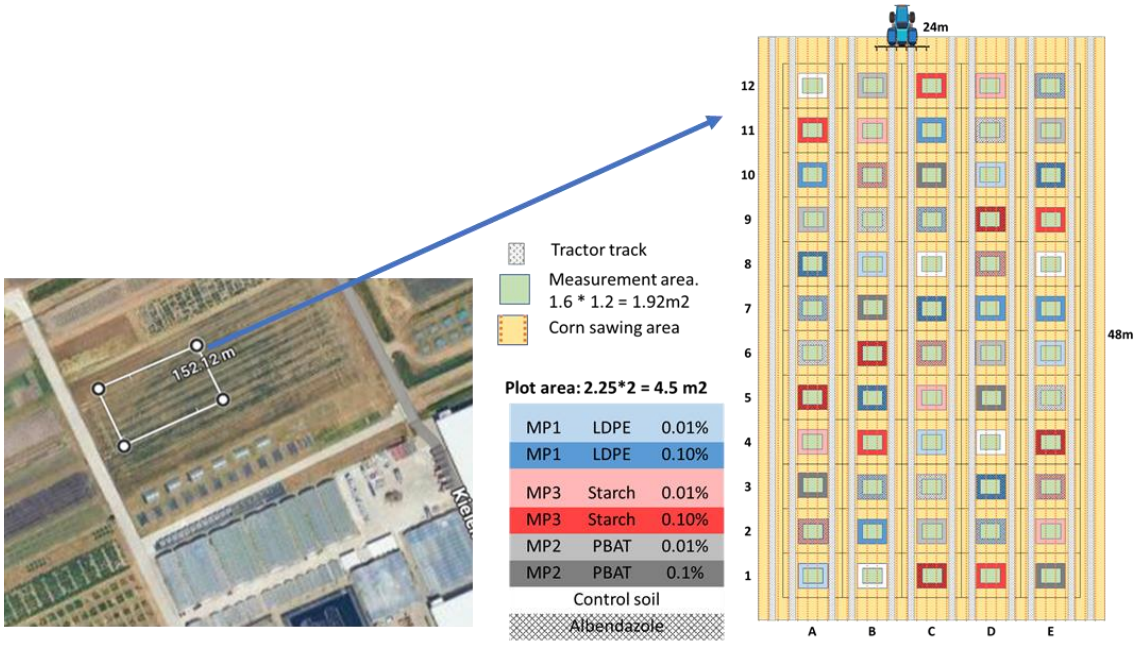

Figure 1: Schematic representation of the Wageningen experimental site

MP was applied on 15 May 2024, followed by maize sowing on 23 May 2024. Germination was assessed on 6 June 2024 to evaluate early establishment under the given conditions. The crop was grown under rainfed conditions and harvested on 3 October 2024.

2.2 DIJON EXPERIMENTAL SITE

The field experiment was carried out during the 2024 growing season at coordinates: 47°18'32.1"N, 5°03'59.4"E (Figure 2). The site experienced natural climatic conditions without supplemental irrigation.

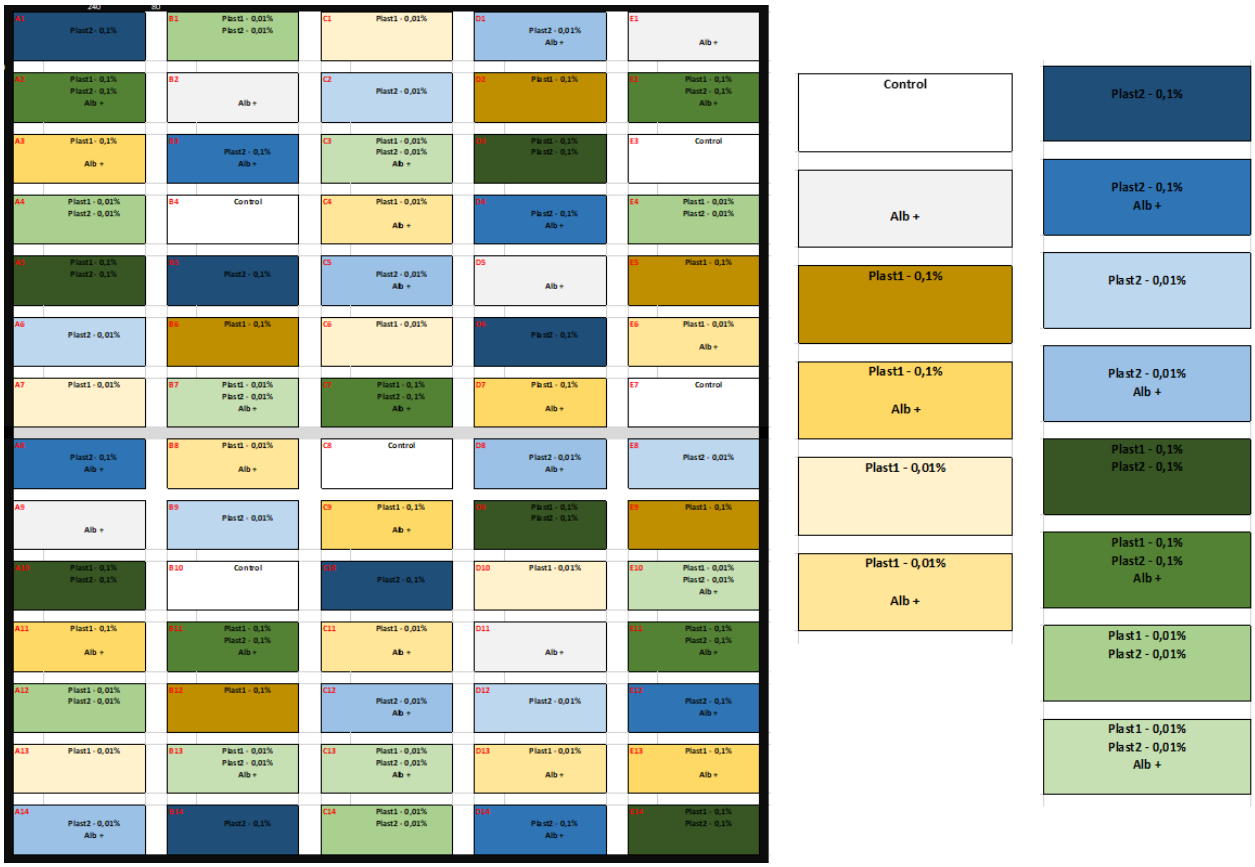

Figure 2: Schematic representation of the Dijon experimental site

MP was applied on 30 May 2024, followed by maize sowing on 4 June and resowing on 24 June 2024. Germination was assessed on 2 July 2024 to early development of plants. The crop was grown under rainfed conditions and harvested on 24 October 2024.

No additional experimental events, water management interventions, or external influences were reported.

2.3 CRETE EXPERIMENTAL SITE

The field experiment was carried out during the 2024 growing season at coordinates: 35°31'54.5"N 24°03'39.6"E (Figure 3). The site experienced natural climatic conditions without supplemental irrigation.

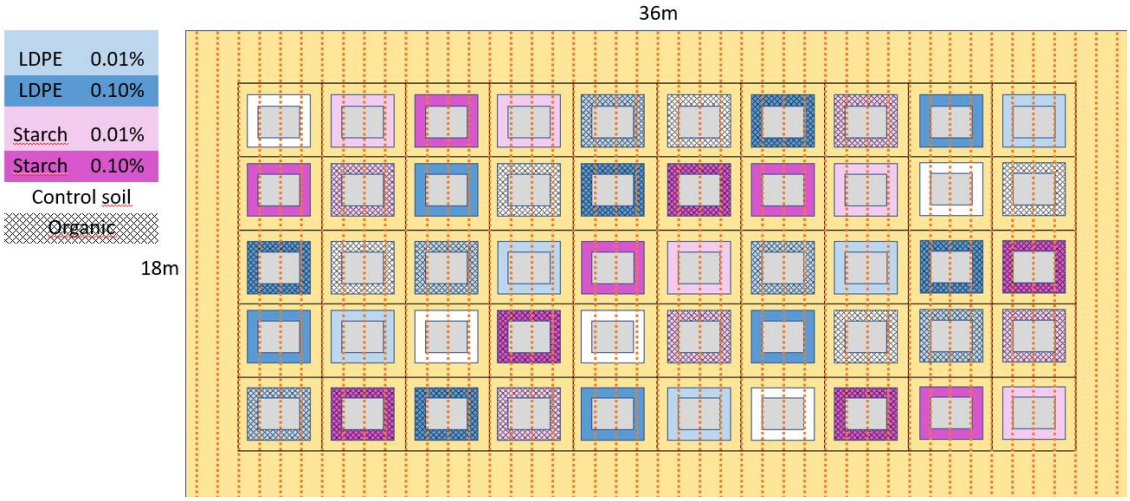

Figure 3: Schematic representation of the Crete experimental site

MP was applied on 23 May 2024, followed by maize sowing on 25 May 2024. Germination was assessed on 12 June 2024 to evaluate early development of plants. The crop was grown under rainfed conditions and harvested on 4 September 2024. No additional experimental events, water management interventions, or external influences were reported.

2.4 FIELD SITES SOIL PROPERTIES

To better understand the environmental conditions influencing soil physical properties, crop performance and soil–plant interactions, soil samples were collected from all three MINAGRIS experimental sites. The physical and chemical properties of these soils are summarized in the table below (Table 1). Analyses included soil texture (sand, silt, clay), pH, organic carbon content, total nitrogen, macro-nutrients (P_2O_5, K_2O, Ca, Mg), and cation exchange capacity (CEC).

The analysis revealed substantial variability in soil characteristics between sites. Crete soil is sandy-clay with moderate fertility and with a slightly acidic pH. Dijon soils have a loam texture with high carbonate and organic matter content, as well with a higher pH and nutrient availability. In contrast, Wageningen soils are predominantly sandy with very low clay content, with acidic pH, and low nutrient retention capacity.

Table 1: Soil properties characterization from the MINAGRIS experimental field site locations: Crete, Dijon and Wageningen

	Experimental field sites		
Soil properties	**Crete**	**Dijon**	**Wageningen**
Sand (%)	52.2	16.8	85.9
Silt – coarse (%)	5.9	16.8	4.0
Silt – fine (%)	8.2	22.3	4.3
Total silt (%)	14.1	39.1	8.3
Clay (%)	33.7	33.6	5.8
Soil type (TRZ)	SCL (sandy-clay-loam)	CL (clay-loam)	LS (loamy-sand)
pH ($CaCl_2$)	6.6	7.4	5.5
Total C [%]	0.93	5.09	1.73
Carbonates [%]	1.0	29.3	1.0
Organic C (C_org) [%]	0.8	1.6	1.6
Organic matter [%]	1.4	2.8	2.8
Total N [%]	0.07	0.15	0.10
C_org / N_total	11.4	10.7	16.0
P_2O_5 [mg/100g]	1.1	13.0	41.6
K_2O [mg/100g]	22.8	27.9	11.5
Ca [mmol_c/100g]	118.41	36.68	3.35
Mg [mmol_c/100g]	2.30	0.93	0.44
K [mmol_c/100g]	1.03	0.83	0.26
Na [mmol_c/100g]	0.19	0.05	0.03
CEC [mmol_c/100g]	15.96	27.98	6.77

3. DATA ANALYSIS

At each site, the effects of selected MP materials—including low-density polyethylene (LDPE), polybutylene adipate terephthalate (PBAT), and starch-based MP were studied under realistic agricultural conditions. Treatments included a control and a single MP dosage (0.1% w/w), each applied with and without a selected veterinary pharmaceutical (Albendazole), in order to evaluate both individual and combined effects on soil and crop systems.

To ensure the quality of the collected data, an initial review and cleaning was performed to a) detect potential anomalies (outliers, environmental disturbances). Outliners were detected with more than 2.0 IQR away from the median of the data. Analysis of the data included plotting both the full dataset (i.e., raw values of all replicates) and the treatment-level means with standard errors (averaged across five replicates for each treatment per location). These visualizations facilitated interpretation and allowed for the detection of outliers or systematic patterns.

The statistical analysis will be performed at the end of the second year of the experiment in order to enable more robust and meaningful comparisons between treatments and across years. This approach was chosen to account for potential inter-annual variability and to ensure that conclusions are based on a more representative dataset. This approach allows for the identification of consistent treatment effects while minimizing the influence of one-off anomalies that may occur due to seasonal variability or external factors. By combining data from both years, the statistical power of the analysis is increased, making the results more robust and reliable. Additionally, this strategy enables direct comparisons between years, helping to determine whether observed effects are stable over time or specific to particular environmental conditions.

4. ANALYSIS OF SOIL PHYSICAL PROPERTIES

At the end of the growing season, from September to October 2024, soil samples were collected from all experimental plots at each study site—Dijon, Wageningen, and Crete—with the purpose of assessing soil physical properties. From each plot, the following samples were taken:

- One undisturbed core soil sample for determining saturated hydraulic conductivity and bulk density (n=60 samples /location)[1](Figure 4 A),
- One undisturbed core for soil water retention analysis (n=60 samples /location)[1]
- One disturbed soil sample for determining the wilting point and soil texture analysis (n=60 samples /location)[1] (Figure 4B).

[1] for this report, only samples with concentration 0.1% of MP and control are analyzed (n=30 samples /location)

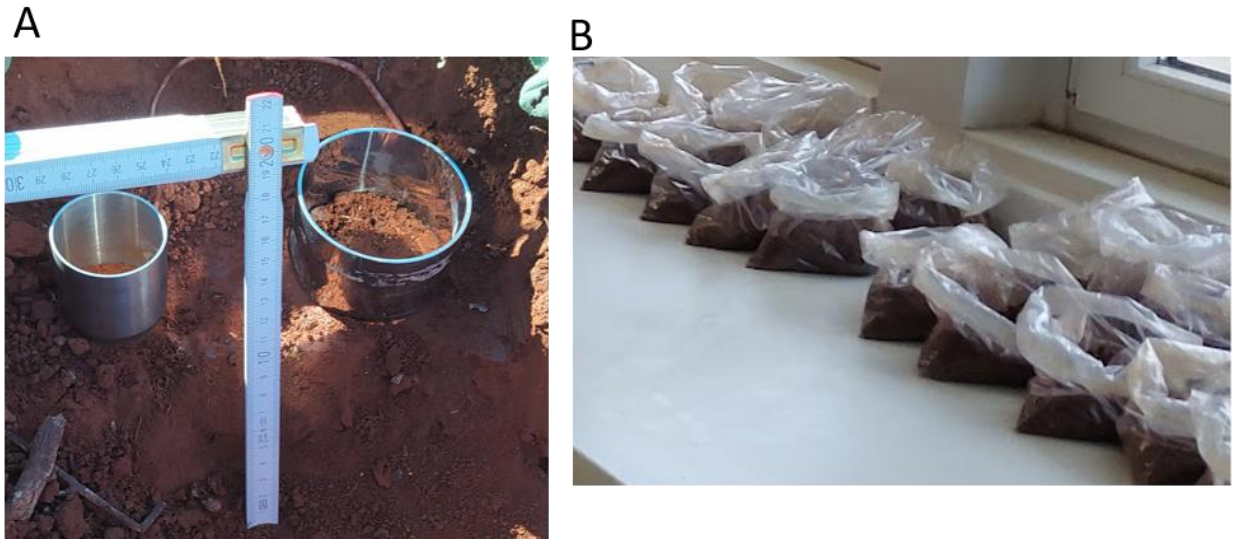

Figure 4: Collected soil samples: A) Undisturbed samples (Kopecky ring left; Hyprop cylinders right) and B) disturbed samples

4.1 SOIL BULK DENSITY

Undisturbed core soil samples were collected from each treatment using Kopecky rings (inner diameter: 2.5 cm; height: 5 cm; volume: 100 cm^3) at a depth of 15-20 cm. Following the measurement of soil water retention, the samples were oven-dried at 105 °C for 48 hours, or until a constant mass was achieved.

Bulk density (ρb), defined as the mass of oven-dried soil per unit volume, was determined for each sample. The calculation followed the (*ISO 11272:2017*):

$$\rho_b = \frac{m_s}{V}$$

where:

where $m_s$is the mass of the dry soil (g) and V is the volume (cm^3).

4.2 SATURATED HYDRAULIC CONDUCTIVITY

4.2.1 Determination of Saturated Hydraulic Conductivity (Ks)

At the end of the first year of the experiment, three undisturbed soil samples were collected from each treatment using Kopecky rings (inner diameter: 2.5 cm; height: 5 cm; volume: 100 cm^3) at a depth of 15-20 cm. The saturated hydraulic conductivity (Ks) was determined using either the constant head or falling head method, depending on the permeability of the soil sample, following the procedures outlined by (Klute & Dirksen, 1986).

For permeable samples, the **constant head method** was applied. Ks was calculated using the following equation:

$$Ks = \frac{V \times L}{t \times \Delta h}$$

where:

- *V* is the volume of water that passed through the soil sample (cm³),
- *L* is the height of the soil sample (cm),
- *t* is the time required for water to pass through the sample (days), and
- *Δh* is the difference in water level between the reservoir and the sample inlet (cm).

Each measurement was repeated five times for accuracy.

For **poorly permeable samples**, the **falling head method** was employed (Klute & Dirksen, 1986). Ks was determined using the following formula:

$$Ks = \frac{a \times L}{\mathrm{A} \times (\mathrm{t2} - \mathrm{t1})} \times ln\frac{h1}{h2}$$

where:

- *a* is the cross-sectional area of the water column in the burette (cm²),
- *L* is the height of the soil sample (cm),
- *A* is the cross-sectional area of the soil sample (cm²),
- $(t_2 - t_1)$ is the elapsed time between two measurements (days), and
- h_1 and h_2 are the water head heights (cm) at times t_1 and t_2, respectively.

Five replicate measurements were conducted for each soil sample to ensure consistency and reliability of the results.

4.3 SOIL WATER RETENTION

4.3.1 Hyprop

At each of the designated plot measurement locations, an undisturbed soil sample was collected prior to sensor installation. Samples were extracted from a depth of 15-20 cm using steel cylinders with a radius of 4 cm, a height of 5 cm, and a total volume of 250 cm³ *(METER Group*, 2023; Shokrana & Ghane, 2020).

The soil water retention characteristics (SWRCs) were determined over a matric potential range from near saturation to approximately –100 kPa using the HYPROP system . This system operates on the evaporation method described by Schindler et al. (2010), allowing for the automated and continuous measurement of both matric potential and sample mass loss during evaporation. These data were used to derive soil water retention curves (*METER Group*, 2023).

4.3.2 Pressure Plate Extractor Method for Wilting Point Determination

To determine the soil water content at the wilting point, the pressure plate extractor method was used in accordance with (*ISO 11274:2019*). The pressure plate system consists of a sealed chamber containing a porous ceramic plate connected to a drainage outlet. Sieved soil samples (<2 mm) were packed into metal rings and saturated before being placed on the ceramic plate within the chamber.

The chamber was then pressurized to −1500 kPa, forcing water out of the soil through the ceramic plate until equilibrium was reached—indicated by the cessation of water flow from the outlet tube. At this point, the samples were removed, weighed, and oven-dried at 105 °C for 24 hours. The dry weights were recorded to calculate the gravimetric water content at the wilting point (WP), following the methodology described by (Jury & Horton, 2004). Each measurement was performed in triplicate.

4.4 SOIL AGGREGATE STABILITY

Soil aggregate stability was assessed using a wet-sieving protocol adapted from Ma et al.(2021) and Six et al.(2000), employing an Eijkelkamp wet sieving apparatus. For each sample, 4 g of air-dried soil (<2 mm) was placed on a 250 µm mesh sieve. Moisture was adjusted to 60% of the soil's field capacity by carefully spraying deionized water onto the soil surface to avoid slaking effects.

The sieving process was performed in two steps:

1. Samples were shaken in distilled water on the 250 µm sieve for 3 minutes. The material retained on the sieve was collected as macroaggregates (MA).
2. The remaining suspension was transferred to a 53 µm mesh sieve and shaken again in distilled water for 3 minutes. Material retained on the 53 µm sieve was collected as microaggregates (mA), and the material passing through was considered the silt and clay (S+C) fraction.

All fractions were oven-dried at 65°C and weighed. The mean weight diameter (MWD) of water-stable aggregates was calculated as:

$$MWD = \frac{\sum(xi \times \omega i)}{\sum \omega i}$$

where xi is the mean diameter of each size fraction and ωi is the corresponding weight.

5. MICROPLASTIC EFFECT ON SOIL PHYSICAL PROPERTIES

Section 4 presents both the complete datasets (i.e., raw values for all experimental units) and the means per treatment per site (calculated as the average of five replicates per treatment at each location) for all the soil physical parameters measured in this research.

5.1 SOIL BULK DENSITY

Figure 5 and 6, present soil bulk density values (g/cm³) across the three experimental locations (Crete, Dijon, and Wageningen).

No significant differences in soil bulk density were observed either within locations (i.e., between treatments) compared to the control. This suggests that, the soil was homogenously prepared and packed consistently across all plots and treatments, confirming proper and uniform field setup. At the tested MP concentration (0.1%), none of the selected MP types had a measurable effect on soil bulk density under field conditions. Similarly, the presence of albendazole did not show any clear or consistent impact. We can conclude that soil sampling and plot establishment were reliable conducted, resulting in a homogeneous soil structure (as seen at Figures 5 and 6). MP input at 0.1%, did not alter soil compaction as reflected by bulk density measurements.

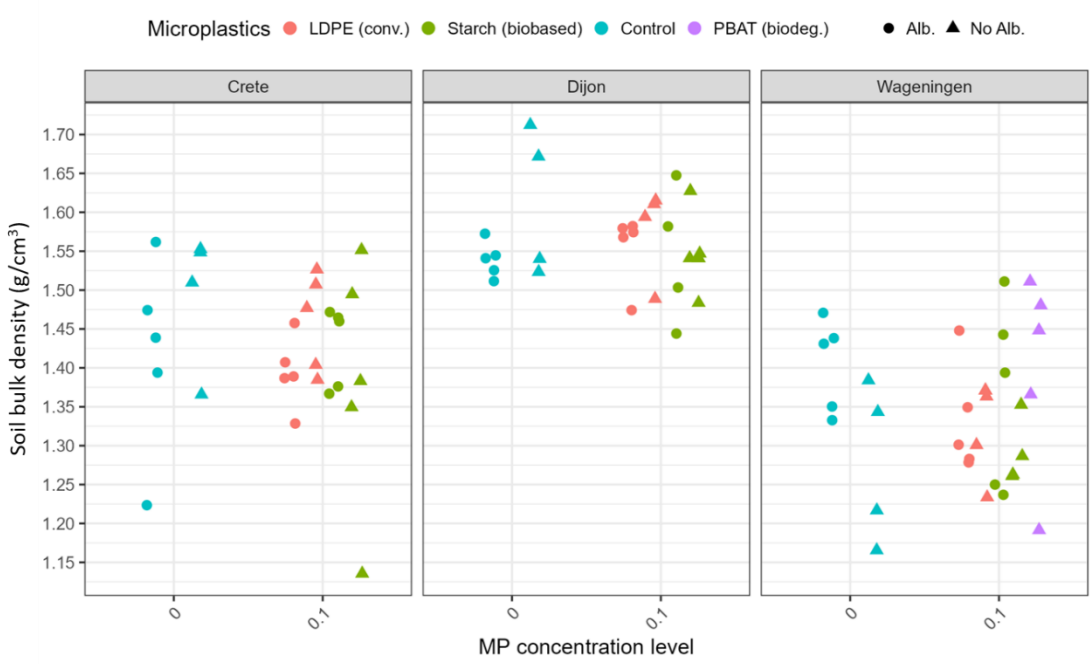

Figure 5: Soil bulk density values (g/cm³) across the three experimental locations (Crete, Dijon, and Wageningen). Each experimental site included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

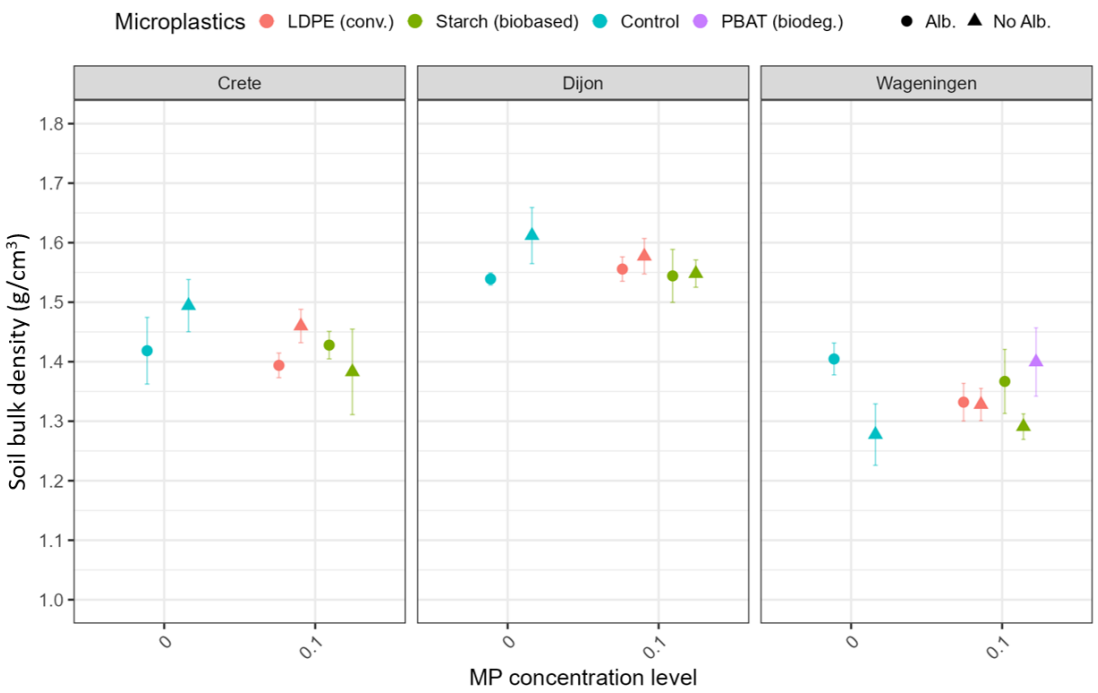

Figure 6: Soil bulk density mean values (g/cm³) with standard errors (SE), calculated with five replicates per treatment per location (Crete, Dijon, and Wageningen). Each experimental site included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

The measured soil bulk density values show relatively low variability within-treatments, as reflected in the coefficient of variation, which mostly remained below 10%. The lowest variability was observed in Dijon, particularly in the control treatment with Albendazole (Cv = 1.49%), indicating highly consistent results (Table 1, annex 1).

In Crete, soil bulk density values ranged from 1.38 to 1.49 g/cm^3 across treatments, with the highest variability (Cv = 11.62%) found in the starch-based treatment without Albendazole. The presence of MP and Albendazole showed only minor and inconsistent effects on the mean soil bulk density.

In Dijon, soil bulk density values were consistently higher than in Crete and Wageningen, ranging from 1.54 to 1.61 (g/cm^3) with minimal variability. The highest soil bulk density was observed in the control treatment without Albendazole (1.61 g/cm^3).

In Wageningen, soil bulk density values ranged from 1.28 to 1.40 g/cm^3), with the control without Albendazole showing the lowest mean and one of the highest coefficients of variation (Cv = 8.07%). Similar soil bulk density values were observed among the MP treatments, regardless of MP type or Albendazole addition.

Overall, the data suggest that neither the addition of MP (at concentration 0.1%) nor Albendazole had a substantial or systematic effect on soil bulk density. The observed variations appear to be driven more by location-specific soil properties than by the experimental treatments. **These preliminary findings will be further examined after the completion of the two-year experiment, when a comprehensive statistical analysis will be conducted to allow for more robust and conclusive comparisons.**

5.2 HYDRAULIC CONDUCTIVITY

Although visible differences in Ksat that can be observed between treatments within individual locations (Figure 6 and 7), the overall variability within treatments is high and comparable to the differences between treatments. Due to this high within-treatment variation, if statistical test would be performed, they would not likely confirm significant differences among treatments. The observed variability is likely to be related to the inherent sensitivity of method for saturated hydraulic conductivity, which is strongly connected to small-scale heterogeneities. While some treatment- differences appear visually, they should be interpreted cautiously due to the high variability. Overall, the data suggest that at the applied MP concentration, no consistent effect on Ksat can be confirmed across the sites.

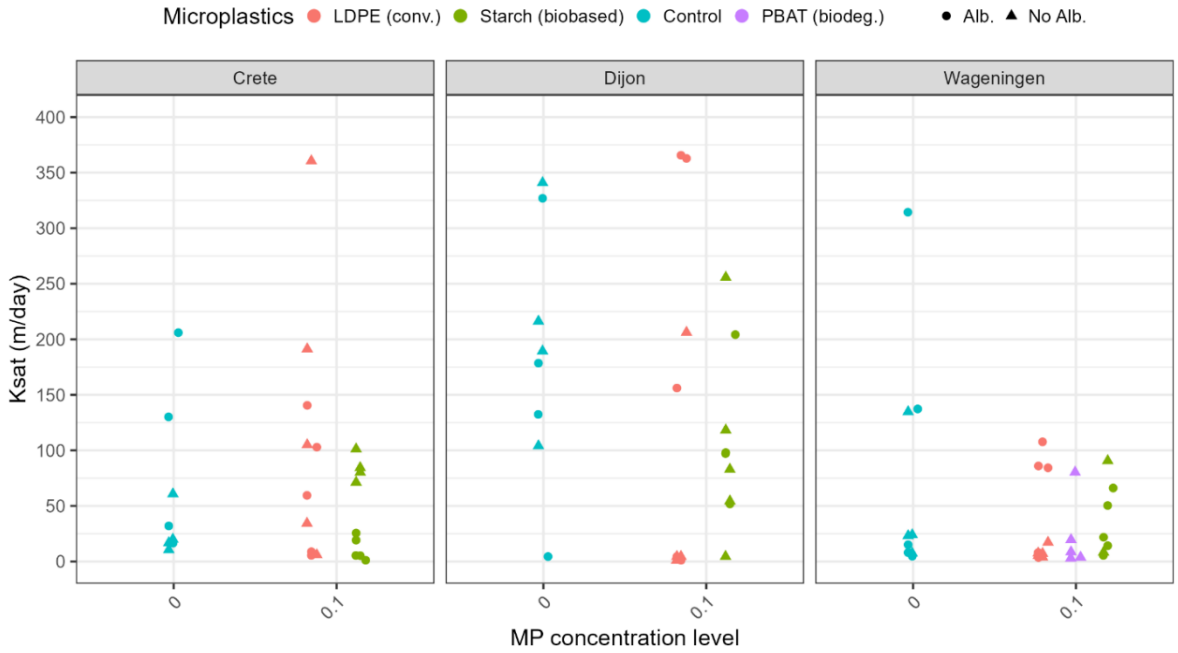

Figure 7: Saturated hydraulic conductivity (Ksat, in m/day) measured across the three experimental locations (Crete, Dijon, and Wageningen). Each treatment included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

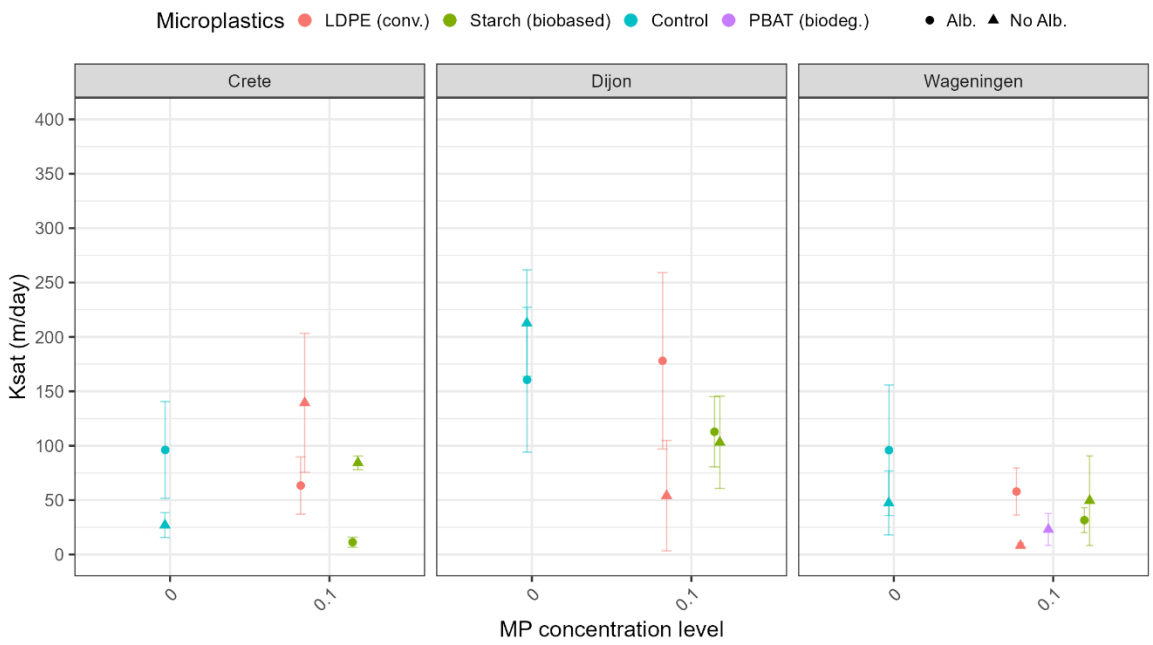

Figure 8: Saturated hydraulic conductivity (Ksat, in m/day) mean per treatment, with standard errors (SE), calculated with the five replicates per treatment per location (Crete, Dijon, and Wageningen). Each experimental site included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

Results shown in Table 2, Annex 1, reveal high variability in Ksat values, particularly in Crete and Wageningen. Coefficients of variation frequently exceeded 80%, and in some cases surpassed 100%, indicating substantial heterogeneity within treatments. This variability limits the ability to detect statistically robust treatment effects.

In Crete, Ksat values ranged widely from as low as 11.28 m/day (starch + Alb.) to as high as 139.41 m/day (LDPE, no Alb.). While LDPE tended to increase conductivity compared to the control in the absence of Alb., the starch-based MP showed opposite trends depending on the presence of Albendazole.

In Dijon, control experimental units displayed relatively high Ksat values. Control showed the highest conductivity (212.67 m/day). The addition of LDPE produced inconsistent results: in the presence of Alb., Ksat remained high (178.03 m/day, while in its absence, a marked decrease was observed (54.05 m/day, with high variability (Cv = 187.71%). Starch-based MP had moderate effects, with Ksat values clustering around 100–110 m/day.

In Wageningen, Ksat values were generally lower and more variable. Control treatments ranged from 47.32 to 95.91 m/day. Interestingly, LDPE in the absence of Albendazole resulted in a substantial reduction in conductivity (8.21 m/day), whereas the presence of Alb. led to a higher mean value (57.90 m/day). PBAT treatments produced variable results (mean = 23.01 m/day; Cv = 142.20%), and starch-based MP showed moderate Ksat values with Alb. (31.58 m/day) and a slightly higher mean without Alb. (49.50 m/day), although based on only two replicates.

In summary, the data show that saturated hydraulic conductivity was highly sensitive to both soil type and treatment, with no consistent pattern across locations or MP types. The pronounced variability observed,

particularly within certain treatments, underscores the complexity of soil–water interactions and the challenges in identifying clear treatment effects. This variability likely reflects the influence of inherent soil properties—such as texture, structure, and porosity—as well as local heterogeneity and site-specific conditions. The extreme variability observed in several treatments highlights the challenges in detecting differences and suggests that site-specific factors and soil heterogeneity likely played a major role in determining water flow characteristics under the tested conditions. **Following the completion of the two-year experiment, these preliminary results will be subjected to thorough statistical analysis to strengthen the validity of the comparisons and conclusions.**

5.3 SOIL WATER RETENTION

Figure 8 and 9 show raw data and means with standard errors (SE) for soil water retention properties at various matric potentials (pF 0–4.2), measured with five replicates per treatment at three locations (Crete, Dijon, and Wageningen). The observed differences between treatments and the control are comparable to the overall data variability, which is expected due to the MP concentration applied (0.1%). Major differences are visible between experimental locations rather than among treatments within each location. This indicates that water retention differs significantly between locations.

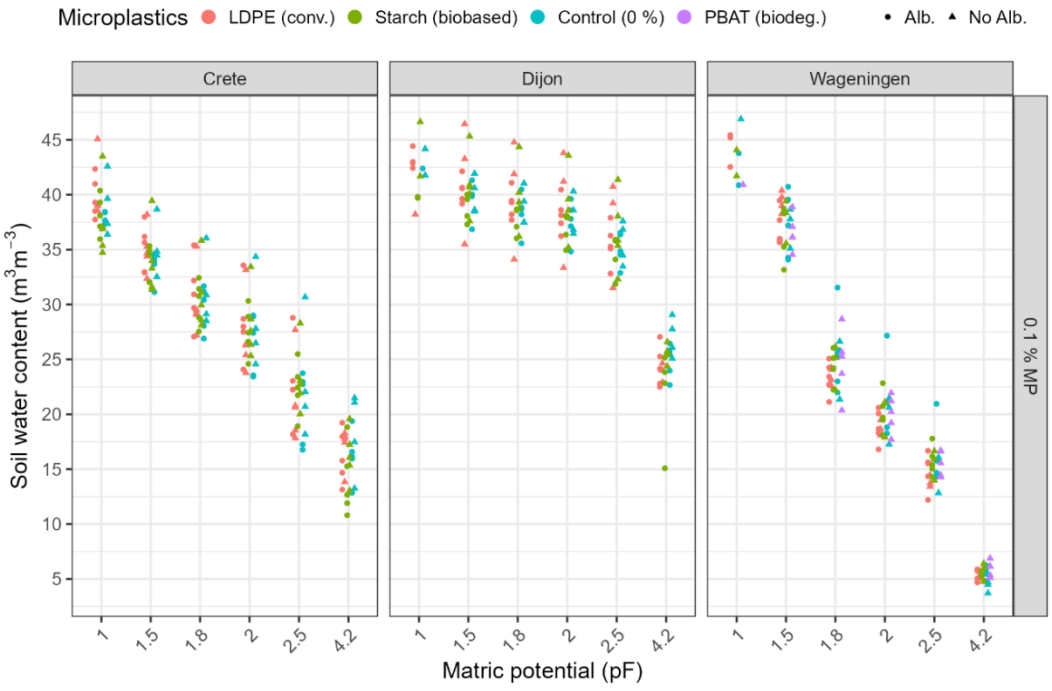

Figure 9: Raw data of soil water–retention at different matric potentials (pF values from 0 to 4.2), measured across three experimental locations (Crete, Dijon, and Wageningen). Each experimental site included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

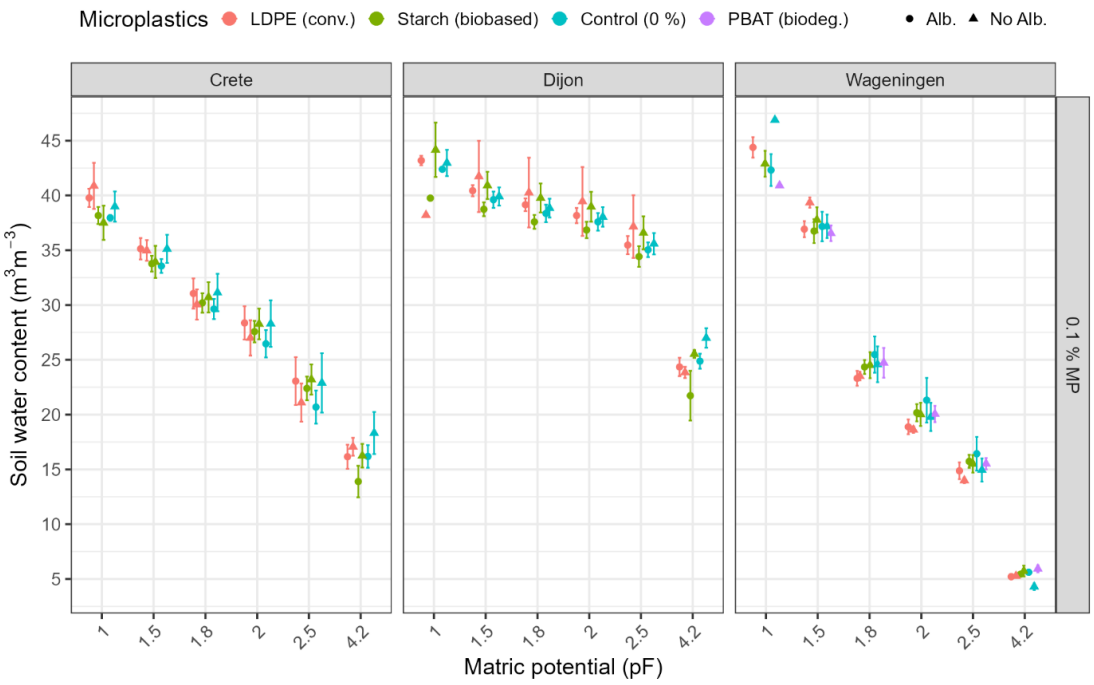

Figure 10: Means with standard errors (SE), calculated across the five replicates of soil water–retention at different matric potentials (pF values from 0 to 4.2), measured across three experimental locations (Crete, Dijon, and Wageningen). Each experimental site included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

Across all locations, the results of the water retention curves showed typical patterns (Table 3, Annex 1): water content decreased with increasing pF, reflecting a reduction in soil moisture as suction increased. However, treatment effects on water retention were subtle and highly site-dependent.

In Crete, control treatment followed a clear pattern of declining water content from ~38% at pF 1 to ~16% at pF 4.2. The coefficients of variation increased at higher suctions, reaching over 20% at pF 2.5 and 4.2, especially in the absence of Albendazole.

The addition of LDPE and starch-based MP slightly increased water content at lower pF values compared to control. However, the differences diminished with increasing suction. Notably, variability (Cv) remained high in several treatments, especially at pF ≥ 2.5, suggesting heterogeneity in soil structure or MP distribution.

In Dijon, soil water retention showed very low variability, with most Cv values remaining below 6%, especially in control treatments. MP additions had minimal influence on retention across all pF levels. LDPE and starch-based MPs produced retention values similar to the control, and no consistent effect of Albendazole was observed. This indicates that in this soil type, the structure and texture largely governed moisture patterns, overshadowing any MP-related effects.

In Wageningen, soils displayed more pronounced declines in water content at higher pF levels (e.g., from ~42% at pF 1 to ~5% at pF 4.2). Variability was moderate at low suction but increased notably at higher pF values in certain treatments.

Among MP types, PBAT and starch-based MPs exhibited similar water retention patterns to LDPE. Differences between Alb. and No Alb. treatments were minor. The effects of MP addition were more visible at lower pF levels, but differences remained within the range of standard errors, and no consistent trend across treatments was evident.

Overall, the results show that soil texture and structure (i.e., location) had a stronger influence on water retention than either microplastics or albendazole. The effects of MPs on water retention were limited, especially at higher suctions (pF 2–4.2), suggesting that, at the tested concentration (0.1%), MP did not significantly impact on water-holding capacity. Moreover, also the addition of Albendazole had no systematic effect on water retention across locations or MP types. **These preliminary observations will be further examined after the completion of the second-year experiment, when a comprehensive statistical analysis will be conducted to allow for more robust and conclusive comparisons.**

5.4 SOIL AGGREGATE STABILITY

Figures 10 and 11 present the raw mean weight diameter (MWD) values and treatment means (± standard errors), respectively. Overall, the results showed no statistically significant effects of MP or albendazole on MWD at any of the three locations. While some differences between treatments were observed, particularly in Dijon, these did not exceed the natural variability within replicates and were not consistently reproduced across sites.

The highest MWD values were generally recorded in Dijon, suggesting inherently higher soil aggregate stability at this site, likely due to its soil properties (e.g., texture, organic matter). In contrast, Crete exhibited the lowest MWD values overall. The addition of MP, regardless of their type or degradability, did not systematically increase or decrease aggregate stability. Similarly, the presence of albendazole had no consistent effect on MWD values, either alone or in combination with MP.

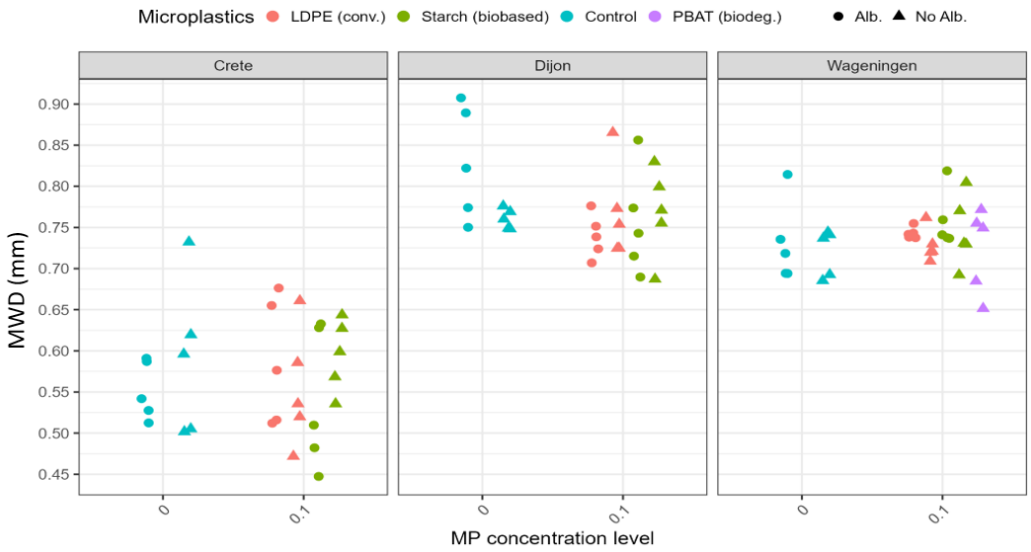

Figure 11: Raw data of the mean weight diameter (MWD in mm) of water-stable aggregates measured across three experimental locations (Crete, Dijon, and Wageningen). Each experimental site included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

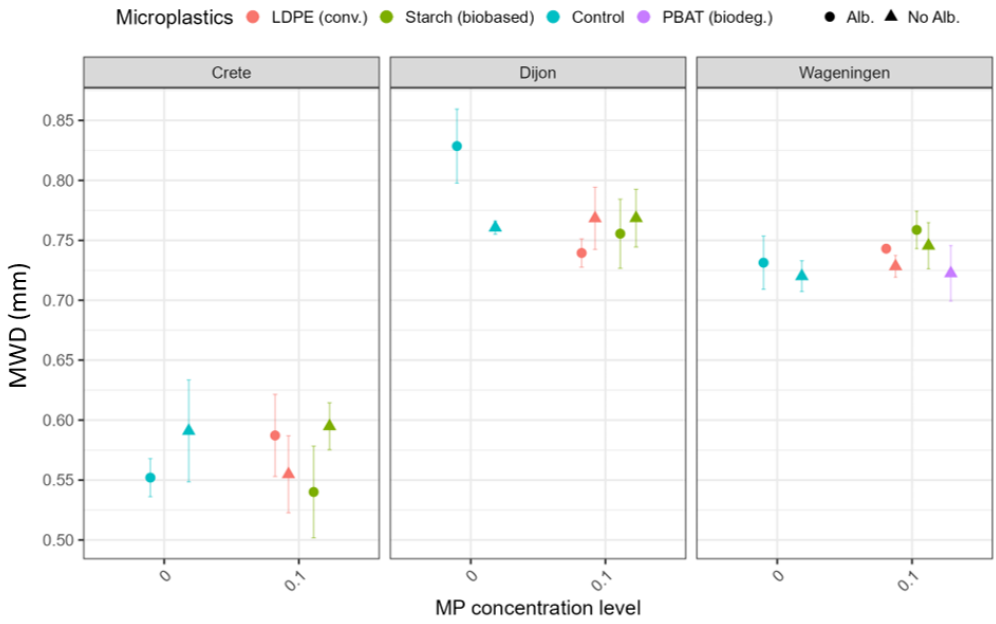

Figure 12: Means with standard errors (SE) of the mean weight diameter (MWD in mm) of the water-stable aggregates, measured across three experimental locations (Crete, Dijon, and Wageningen). Each experimental site included a control and MP additions (LDPE, PBAT, starch-based), with and without the veterinary pharmaceutical albendazole (Alb., No Alb.). The MP concentration level was 0.1%.

Table 4 (Annex 1) presents how soil aggregate stability values in Crete, were generally, the lowest among the three locations, ranging between 0.54 mm and 0.59 mm. Both Albendazole (Alb.) and No Alb. treatments showed similar mean values. For example, the Control treatment had mean values of 0.55 mm

(Alb.) and 0.59 mm (No Alb.), while LDPE and starch-based microplastics showed similar ranges without clear improvement or decline. Coefficients of variation (CV) were relatively high, especially in the No Alb. Control treatment (16.09%), indicating greater variability within replicates. This suggests that microplastic addition and Alb presence had limited and inconsistent effects on aggregate stability under the environmental conditions of Crete.

Dijon soils exhibited the highest aggregate stability overall, with means ranging from 0.74 mm to 0.83 mm. The Alb. Control treatment showed the highest mean stability (0.83 mm), with slightly lower values observed when microplastics were introduced (LDPE: 0.74–0.77 mm, Starch: 0.76–0.77 mm). Variability was lower than in Crete, with CVs mostly below 9%, indicating more uniform responses across replicates. The presence of albendazole did not significantly alter aggregate stability. LDPE treatments showed a slight decrease on aggregate stability compared to control. These results suggest that soils in Dijon have a naturally higher aggregate stability, with marginal influence of treatments tested.

Aggregate stability in Wageningen is ranging from 0.72 mm to 0.76 mm. The highest stability was seen with the Alb-Starch treatment (0.76 mm), closely followed by the Alb. Control and LDPE treatments. PBAT (a biodegradable microplastic) treatments had similar stability (0.72 mm), comparable to the control. The CV values were the lowest among the three locations, mostly under 8%, suggesting consistent results. No substantial differences were detected between Alb. and No Alb. treatments, or between MP types, indicating limited impact on soil aggregate stability in this location.

Overall, the data indicate that soil aggregate stability is primarily influenced by soil type per location, rather than the treatments tested. **These initial findings will be revisited upon completion of the second-year experiment, at which point a comprehensive statistical analysis will be carried out to enable more reliable and definitive comparisons.**

6. GENERAL CONCLUSIONS

The findings of our study indicate that neither the incorporation of MP nor the veterinary pharmaceutical anthelmintic, albendazole (Alb.) at a concentration of 0.1% (w/w) and 1 mg/kg resulted with significant impact on the soil physical properties measured in this research.

After the first year of the field experiment, this study did not detect any significant -driven effect on soil physical properties, produced by MP or the veterinary drug. There is a huge variability among samples, which can be explained by the natural heterogeneity among the soils at the different locations.

These results are consistent with previous research, which has reported a minimal short-term influence of MP—particularly at low concentrations—on parameters such as bulk density. However, some studies have noted that over extended periods, especially when fiber- or film-shaped MPs are involved, these particles may disrupt soil aggregation and structural integrity, potentially leading to changes in bulk density (Železnikar et al., 2025a; Büks & Kaupenjohann, 2020).

The concentrations applied in this study, as well as in several recent experiments (Lozano et al., 2021; Qi et al., 2020a; Yu et al., 2023; Zhang et al., 2019), exceed typical environmental levels detected in agricultural soils so far. While 0.1% (w/w) is commonly used in experimental setups, actual contamination levels in agricultural fields are generally much lower, often represented by a few hundred to several thousand particles per kilogram found in agricultural soils and soils in urban areas (Piehl et al., 2018; Scheurer & Bigalke, 2018)—translating to concentrations well below 0.1% (w/w). Exceptions may occur in hotspots, highly polluted areas, such as those exposed to frequent plastic mulching, or those with high application of polluted fertilizers (ie. sludge or compost), or located near urban canter's, where concentrations may reach or exceed 1% (Li et al., 2020). Still, biodegradable plastics are less likely to accumulate to such extents due to their capacity to break down over time.

Furthermore, inconsistencies between laboratory and field-based studies are increasingly evident in the literature. Laboratory investigations (e.g., Yu & Flury, 2024; Qi et al., 2020b) often benefit from tightly controlled conditions, standardized soil substrates, and predefined MP dosages. While such setups allow precise quantification of impacts, they may not fully capture the complexity of natural systems. Field studies, such as our 3 location experimental sites, or the studies of Griffin-LaHue et al. (2022) or Büks & Kaupenjohann (2020), are inherently more variable, due to site-specific factors such as soil type, historical land use, and environmental fluctuations. These complexities underscore the importance of long-term monitoring and contextual understanding when evaluating the real-world consequences of MP contamination in soils.

In conclusion, while no significant effects were observed in this first year of field experiment, a series of continued field observations and expanded temporal scales will be essential to fully understand the cumulative and potentially delayed impacts of MPs and other emerging contaminants on soil health.

As statistical analysis will be conducted only after the completion of the second year of the experiment, it allows for stronger comparisons by incorporating data across both years. This strategy reduces the influence of short-term variability and increases the reliability of observed treatment effects, especially in field-based or semi-controlled studies where environmental conditions may fluctuate.

7. LIST OF REFERENCES

Babaei, A. A., Reshadatian, N., & Feizi, R. (2024). A state of the art-mini review on the sources, contamination, analysis, and consequences of microplastics in water. *Results in Engineering*, *23*, 102827. https://doi.org/10.1016/j.rineng.2024.102827

Büks, F., & Kaupenjohann, M. (2020). *Global concentrations of microplastic in soils, a review* [Preprint]. Soils and the human environment. https://doi.org/10.5194/soil-2020-50

Dissanayake, P. D., Kim, S., Sarkar, B., Oleszczuk, P., Sang, M. K., Haque, M. N., Ahn, J. H., Bank, M. S., & Ok, Y. S. (2022). Effects of microplastics on the terrestrial environment: A critical review. *Environmental Research*, *209*, 112734. https://doi.org/10.1016/j.envres.2022.112734

Fan, P., Yu, H., Xi, B., & Tan, W. (2022). A review on the occurrence and influence of biodegradable microplastics in soil ecosystems: Are biodegradable plastics substitute or threat? *Environment International*, *163*, 107244. https://doi.org/10.1016/j.envint.2022.107244

Gao, D., Li, X., & Liu, H. (2020). Source, occurrence, migration and potential environmental risk of microplastics in sewage sludge and during sludge amendment to soil. *Science of The Total Environment*, *742*, 140355. https://doi.org/10.1016/j.scitotenv.2020.140355

Gong, J., & Xie, P. (2020). Research progress in sources, analytical methods, eco-environmental effects, and control measures of microplastics. *Chemosphere*, *254*, 126790. https://doi.org/10.1016/j.chemosphere.2020.126790

Griffin-LaHue, D., Ghimire, S., Yu, Y., Scheenstra, E. J., Miles, C. A., & Flury, M. (2022). In-field degradation of soil-biodegradable plastic mulch films in a Mediterranean climate. *Science of The Total Environment*, *806*, 150238. https://doi.org/10.1016/j.scitotenv.2021.150238

Guo, Z., Li, P., Yang, X., Wang, Z., Lu, B., Chen, W., Wu, Y., Li, G., Zhao, Z., Liu, G., Ritsema, C., Geissen, V., & Xue, S. (2022). Soil texture is an important factor determining how microplastics affect soil

hydraulic characteristics. *Environment International*, *165*, 107293. https://doi.org/10.1016/j.envint.2022.107293

Hanif, M. N., Aijaz, N., Azam, K., Akhtar, M., Laftah, W. A., Babur, M., Abbood, N. K., & Benitez, I. B. (2024). Impact of microplastics on soil (physical and chemical) properties, soil biological properties/soil biota, and response of plants to it: A review. *International Journal of Environmental Science and Technology*, *21*(16), 10277–10318. https://doi.org/10.1007/s13762-024-05656-y

Hassan, J., Rajib, M. M. R., Sarker, U., Akter, M., Khan, M. N.-E.-A., Khandaker, S., Khalid, F., Rahman, G. K. M. M., Ercisli, S., Muresan, C. C., & Marc, R. A. (2022). Optimizing textile dyeing wastewater for tomato irrigation through physiochemical, plant nutrient uses and pollution load index of irrigated soil. *Scientific Reports*, *12*(1). Scopus. https://doi.org/10.1038/s41598-022-11558-1

Hoang, V.-H., Nguyen, M.-K., Hoang, T.-D., Ha, M. C., Huyen, N. T. T., Bui, V. K. H., Pham, M.-T., Nguyen, C.-M., Chang, S. W., & Nguyen, D. D. (2024). Sources, environmental fate, and impacts of microplastic contamination in agricultural soils: A comprehensive review. *Science of The Total Environment*, *950*, 175276. https://doi.org/10.1016/j.scitotenv.2024.175276

Hu, K., Tian, W., Yang, Y., Nie, G., Zhou, P., Wang, Y., Duan, X., & Wang, S. (2021). Microplastics remediation in aqueous systems: Strategies and technologies. *Water Research*, *198*, 117144. https://doi.org/10.1016/j.watres.2021.117144

ISO 11272:2017(en), Soil quality—Determination of dry bulk density. (n.d.). Retrieved 10 April 2024, from https://www.iso.org/obp/ui/en/#iso:std:iso:11272:ed-2:v1:en

ISO 11274:2019(en), Soil quality—Determination of the water-retention characteristic—Laboratory methods. (n.d.). Retrieved 10 April 2024, from https://www.iso.org/obp/ui/en/#iso:std:iso:11274:ed-2:v1:en

Jin, T., Tang, J., Lyu, H., Wang, L., Gillmore, A. B., & Schaeffer, S. M. (2022). Activities of Microplastics (MPs) in Agricultural Soil: A Review of MPs Pollution from the Perspective of Agricultural Ecosystems.

Journal of Agricultural and Food Chemistry, *70*(14), 4182–4201. https://doi.org/10.1021/acs.jafc.1c07849

Jury, W. A., & Horton, R. (2004). *Soil Physics*. John Wiley & Sons.

Klute, A., & Dirksen, C. (1986). Hydraulic conductivity and diffusivity. Laboratory methods. *Methods of Soil Analysis - Part 1. Physical and Mineralogical Methods*, 687–734. https://doi.org/10.2136/sssabookser5.1.2ed.c28

Kumar, M., Xiong, X., He, M., Tsang, D. C. W., Gupta, J., Khan, E., Harrad, S., Hou, D., Ok, Y. S., & Bolan, N. S. (2020). Microplastics as pollutants in agricultural soils. *Environmental Pollution*, *265*, 114980. https://doi.org/10.1016/j.envpol.2020.114980

Li, J., Song, Y., & Cai, Y. (2020). Focus topics on microplastics in soil: Analytical methods, occurrence, transport, and ecological risks. *Environmental Pollution*, *257*, 113570. https://doi.org/10.1016/j.envpol.2019.113570

Lozano, Y. M., Lehnert, T., Linck, L. T., Lehmann, A., & Rillig, M. C. (2021). Microplastic Shape, Polymer Type, and Concentration Affect Soil Properties and Plant Biomass. *Frontiers in Plant Science*, *12*. https://doi.org/10.3389/fpls.2021.616645

Ma, R., Hu, F., Liu, J., & Zhao, S. (2021). Evaluating the effect of soil internal forces on the stability of natural soil aggregates during vegetation restoration. *Journal of Soils and Sediments*, *21*(9), 3034–3043. https://doi.org/10.1007/s11368-021-03011-z

Manuals—METER Group. (2023, June 5). https://metergroup.com/support/downloads/manuals/

Meng, K., Harkes, P., Lwanga, E. H., & Geissen, V. (2024). Microplastics exert minor influence on bacterial community succession during the aging of earthworm (Lumbricus terrestris) casts. *Soil Biology and Biochemistry*, *195*, 109480. https://doi.org/10.1016/j.soilbio.2024.109480

MINAGRIS - Home. (n.d.). Retrieved 27 February 2024, from https://www.minagris.eu/

Nourozi, N., Massahi, T., Nouri, M., Mardani, M., & Hossini, H. (2024). A systematic review of the occurrence of microplastics in compost: Understanding the abundance, sources, characteristics and ecological risk. *Results in Engineering*, *24*, 103639. https://doi.org/10.1016/j.rineng.2024.103639

Piehl, S., Leibner, A., Löder, M. G. J., Dris, R., Bogner, C., & Laforsch, C. (2018). Identification and quantification of macro- and microplastics on an agricultural farmland. *Scientific Reports*, *8*(1), 17950. https://doi.org/10.1038/s41598-018-36172-y

Plastics Europe • Enabling a sustainable future. (n.d.). Plastics Europe. Retrieved 9 December 2021, from https://plasticseurope.org/

Qi, Y., Beriot, N., Gort, G., Huerta Lwanga, E., Gooren, H., Yang, X., & Geissen, V. (2020a). Impact of plastic mulch film debris on soil physicochemical and hydrological properties. *Environmental Pollution*, *266*, 115097. https://doi.org/10.1016/j.envpol.2020.115097

Qi, Y., Beriot, N., Gort, G., Huerta Lwanga, E., Gooren, H., Yang, X., & Geissen, V. (2020b). Impact of plastic mulch film debris on soil physicochemical and hydrological properties. *Environmental Pollution*, *266*, 115097. https://doi.org/10.1016/j.envpol.2020.115097

Sajjad, M., Huang, Q., Khan, S., Khan, M. A., Liu, Y., Wang, J., Lian, F., Wang, Q., & Guo, G. (2022). Microplastics in the soil environment: A critical review. *Environmental Technology & Innovation*, *27*, 102408. https://doi.org/10.1016/j.eti.2022.102408

Santis, A., Arbeláez, O., Cardenas, L. A., Castellanos, J., & Velasquez, P. (2024). Optimizing Cr(VI) Reduction in Plastic Chromium Plating Wastewater: Particle Size, Irradiation, Titanium Dose. *Emerging Science Journal*, *8*(1), Article 1.

Scheurer, M., & Bigalke, M. (2018). Microplastics in Swiss Floodplain Soils. *Environmental Science & Technology*, *52*(6), 3591–3598. https://doi.org/10.1021/acs.est.7b06003

Shokrana, M. S. B., & Ghane, E. (2020). Measurement of soil water characteristic curve using HYPROP2. *MethodsX*, *7*, 100840. https://doi.org/10.1016/j.mex.2020.100840

Silva, A. L. P., Prata, J. C., Duarte, A. C., Soares, A. M. V. M., Barceló, D., & Rocha-Santos, T. (2021). Microplastics in landfill leachates: The need for reconnaissance studies and remediation technologies. *Case Studies in Chemical and Environmental Engineering*, *3*, 100072. https://doi.org/10.1016/j.cscee.2020.100072

Six, J., Elliott, E. T., & Paustian, K. (2000). Soil structure and soil organic matter: II. A normalized stability index and the effect of mineralogy. *Soil Science Society of America Journal*, *64*, 1042–1049.

Walenna, M. A., Hanami, Z. A., Hidayat, R., Damayanti, A. D., Notodarmojo, S., Kurniaty, & Caroles, L. (2024). Examining Soil Microplastics: Prevalence and Consequences Across Varied Land Use Contexts. *Civil Engineering Journal*, *10*(4), Article 4. https://doi.org/10.28991/CEJ-2024-010-04-017

WANG, H.-J., WANG, J., & YU, X. (2022). Wastewater irrigation and crop yield: A meta-analysis. *Journal of Integrative Agriculture*, *21*(4), 1215–1224. Scopus. https://doi.org/10.1016/S2095-3119(21)63853-4

Wang, W., Ge, J., Yu, X., & Li, H. (2020). Environmental fate and impacts of microplastics in soil ecosystems: Progress and perspective. *Science of The Total Environment*, *708*, 134841. https://doi.org/10.1016/j.scitotenv.2019.134841

Wang, Z., Li, W., Li, W., Yang, W., & Jing, S. (2023). Effects of microplastics on the water characteristic curve of soils with different textures. *Chemosphere*, *317*, 137762. https://doi.org/10.1016/j.chemosphere.2023.137762

Yu, Y., Battu, A. K., Varga, T., Denny, A. C., Zahid, T. Md., Chowdhury, I., & Flury, M. (2023). Minimal Impacts of Microplastics on Soil Physical Properties under Environmentally Relevant Concentrations.

Environmental Science & Technology, *57*(13), 5296–5304. https://doi.org/10.1021/acs.est.2c09822

Yu, Y., & Flury, M. (2024). Unlocking the Potentials of Biodegradable Plastics with Proper Management and Evaluation at Environmentally Relevant Concentrations. *Npj Materials Sustainability*, *2*(1), 1–7. https://doi.org/10.1038/s44296-024-00012-0

Železnikar, Š., Drobne, D., Hočevar, M., Noč, M., & Pintar, M. (2025a). Soil water repellency of two disturbed soils contaminated with different agricultural microplastics tested under controlled laboratory conditions. *Geoderma*, *453*, 117124. https://doi.org/10.1016/j.geoderma.2024.117124

Železnikar, Š., Noč, M., Zupanc, V., Lwanga, E. H., Drobne, D., & Pintar, M. (2025b). Impact of conventional and biobased microplastics from mulch films on soil bulk density, hydraulic conductivity and water retention in two different soil types under wetting–drying cycles. *Results in Engineering*, *25*, 104455. https://doi.org/10.1016/j.rineng.2025.104455

Zhang, G. S., Zhang, F. X., & Li, X. T. (2019). Effects of polyester microfibers on soil physical properties: Perception from a field and a pot experiment. *Science of The Total Environment*, *670*, 1–7. https://doi.org/10.1016/j.scitotenv.2019.03.149

8. ANNEX 1

Table 1: Summary of the descriptive statistics for soil bulk density (Density, g/cm^3) across the three experimental locations (Crete, Dijon, and Wageningen), under different treatments with or without the veterinary pharmaceutical albendazole (Alb.). Each treatment included a control (0% MP) and MP additions at 0.1% concentration, using LDPE (conventional), starch-based (biobased), and PBAT (biodegradable, Wageningen only). For each treatment combination, the number of replicates (n), mean (M), standard deviation (SD), standard error (SE), coefficient of variation (Cv, %), and assumed measurement resolution (width) are reported.

Location	Al. /No Alb.	MP type	MP concentration	n	M	SD	SE	Cv	width
Crete	Alb.	Control	Control (0 %)	5	1.42	0.13	0.06	8.83	0.06
Crete	No Alb.	Control	Control (0 %)	4	1.49	0.09	0.04	5.87	0.06
Crete	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	1.39	0.05	0.02	3.32	0.13
Crete	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	1.46	0.06	0.03	4.30	0.13
Crete	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	1.43	0.05	0.02	3.62	0.13
Crete	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	1.38	0.16	0.07	11.62	0.13
Dijon	Alb.	Control	Control (0 %)	5	1.54	0.02	0.01	1.49	0.06
Dijon	No Alb.	Control	Control (0 %)	4	1.61	0.09	0.05	5.85	0.06
Dijon	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	1.56	0.05	0.02	2.95	0.13
Dijon	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	4	1.58	0.06	0.03	3.78	0.13
Dijon	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	4	1.54	0.09	0.04	5.77	0.13
Dijon	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	1.55	0.05	0.02	3.32	0.13
Wageningen	Alb.	Control	Control (0 %)	5	1.40	0.06	0.03	4.26	0.06
Wageningen	No Alb.	Control	Control (0 %)	4	1.28	0.10	0.05	8.07	0.06

Wageningen	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	1.33	0.07	0.03	5.30	0.13
Wageningen	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	1.33	0.06	0.03	4.55	0.13
Wageningen	No Alb.	PBAT (biodeg.)	PBAT (biodeg.) (0.1 %)	5	1.40	0.13	0.06	9.16	0.13
Wageningen	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	1.37	0.12	0.05	8.80	0.13
Wageningen	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	4	1.29	0.04	0.02	3.32	0.13

Table 2: Summary of the hydraulic conductivity (Ksat, m/day) descriptive statistics, across the three experimental locations (Crete, Dijon, and Wageningen), under different treatments with or without the veterinary pharmaceutical albendazole (Alb.). Each experimental site included a control (0% MP) and MP additions at 0.1% concentration, using LDPE (conventional), starch-based (biobased), and PBAT (biodegradable, Wageningen only). For each treatment combination, the number of replicates (n), mean (M), standard deviation (SD), standard error (SE), coefficient of variation (Cv, %), and assumed measurement resolution (width) are reported.

Location	**Alb. /No Alb.**	**MP type**	**MP concentration**	**n**	**M**	**SD**	**SE**	**Cv (%)**	**width**
Crete	Alb.	Control	Control (0 %)	4	96.14	88.86	44.43	92.43	0.06
Crete	No Alb.	Control	Control (0 %)	4	27.01	22.85	11.43	84.61	0.06
Crete	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	63.43	58.86	26.32	92.80	0.13
Crete	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	139.41	142.87	63.89	102.48	0.13
Crete	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	11.28	10.50	4.70	93.08	0.13
Crete	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	4	84.28	12.57	6.29	14.92	0.13
Dijon	Alb.	Control	Control (0 %)	4	160.58	133.13	66.57	82.91	0.06
Dijon	No Alb.	Control	Control (0 %)	4	212.67	97.97	48.99	46.07	0.06
Dijon	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	178.03	181.16	81.02	101.76	0.13
Dijon	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	4	54.05	101.46	50.73	187.71	0.13
Dijon	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	4	112.79	64.66	32.33	57.33	0.13

Dijon	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	103.14	94.91	42.44	92.02	0.13
Wageningen	Alb.	Control	Control (0 %)	5	95.91	134.20	60.02	139.92	0.06
Wageningen	No Alb.	Control	Control (0 %)	4	47.32	58.79	29.39	124.23	0.06
Wageningen	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	57.90	48.51	21.70	83.79	0.13
Wageningen	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	8.21	5.21	2.33	63.51	0.13
Wageningen	No Alb.	PBAT (biodeg.)	PBAT (biodeg.) (0.1 %)	5	23.01	32.72	14.63	142.20	0.13
Wageningen	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	31.58	25.63	11.46	81.17	0.13
Wageningen	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	2	49.50	58.22	41.17	117.62	0.13

Table 3: Summary of the descriptive statistics for soil water retention measured at multiple matric potential levels (pF values ranging from 1 to 4.2) across three locations (Crete, Dijon, and Wageningen), under different treatments involving MP types and the veterinary pharmaceutical albendazole (Alb.). Each treatment included a control (0% MP) and MP additions at 0.1% concentration, using LDPE (conventional), starch-based (biobased), and PBAT (biodegradable, Wageningen only). For each treatment combination, the number of replicates (n), mean (M), standard deviation (SD), standard error (SE), coefficient of variation (Cv, %) are reported.

Location	Alb./No Alb.	MP concentration (%)	Matric potential (pF)	MP type	n	M	SD	SE	Cv (%)
Crete	Alb.	Control (0 %)	1	Control (0 %)	4	37.96	0.54	0.27	1.42
Crete	No Alb.	Control (0 %)	1	Control (0 %)	4	38.98	2.76	1.38	7.08
Crete	Alb.	Control (0 %)	1.5	Control (0 %)	5	33.56	1.40	0.63	4.18
Crete	No Alb.	Control (0 %)	1.5	Control (0 %)	4	35.12	2.57	1.29	7.33
Crete	Alb.	Control (0 %)	1.8	Control (0 %)	5	29.64	2.07	0.93	6.98
Crete	No Alb.	Control (0 %)	1.8	Control (0 %)	4	31.13	3.42	1.71	10.99
Crete	Alb.	Control (0 %)	2	Control (0 %)	5	26.46	2.78	1.24	10.51
Crete	No Alb.	Control (0 %)	2	Control (0 %)	4	28.30	4.25	2.12	15.01
Crete	Alb.	Control (0 %)	2.5	Control (0 %)	5	20.69	3.39	1.51	16.37
Crete	No Alb.	Control (0 %)	2.5	Control (0 %)	4	22.89	5.43	2.71	23.70

Crete	Alb.	Control (0 %)	4.2	Control (0 %)	5	16.18	2.32	1.04	14.32
Crete	No Alb.	Control (0 %)	4.2	Control (0 %)	4	18.32	3.83	1.92	20.92
Crete	Alb.	LDPE (conv.)	1	LDPE (conv.) (0.1 %)	5	39.78	1.88	0.84	4.72
Crete	No Alb.	LDPE (conv.)	1	LDPE (conv.) (0.1 %)	3	40.87	3.65	2.11	8.93
Crete	Alb.	LDPE (conv.)	1.5	LDPE (conv.) (0.1 %)	5	35.13	2.19	0.98	6.22
Crete	No Alb.	LDPE (conv.)	1.5	LDPE (conv.) (0.1 %)	5	34.98	2.11	0.94	6.03
Crete	Alb.	LDPE (conv.)	1.8	LDPE (conv.) (0.1 %)	5	31.05	3.08	1.38	9.92
Crete	No Alb.	LDPE (conv.)	1.8	LDPE (conv.) (0.1 %)	5	30.05	3.07	1.37	10.23
Crete	Alb.	LDPE (conv.)	2	LDPE (conv.) (0.1 %)	5	28.37	3.40	1.52	12.00
Crete	No Alb.	LDPE (conv.)	2	LDPE (conv.) (0.1 %)	5	27.00	3.60	1.61	13.32
Crete	Alb.	LDPE (conv.)	2.5	LDPE (conv.) (0.1 %)	4	23.06	4.38	2.19	18.99
Crete	No Alb.	LDPE (conv.)	2.5	LDPE (conv.) (0.1 %)	5	21.10	3.90	1.75	18.50
Crete	Alb.	LDPE (conv.)	4.2	LDPE (conv.) (0.1 %)	5	16.16	2.46	1.10	15.25
Crete	No Alb.	LDPE (conv.)	4.2	LDPE (conv.) (0.1 %)	5	17.07	1.83	0.82	10.71
Crete	Alb.	Starch (biobased)	1	Starch (biobased) (0.1 %)	5	38.17	1.74	0.78	4.56
Crete	No Alb.	Starch (biobased)	1	Starch (biobased) (0.1 %)	5	37.51	3.49	1.56	9.31
Crete	Alb.	Starch (biobased)	1.5	Starch (biobased) (0.1 %)	5	33.78	1.61	0.72	4.78
Crete	No Alb.	Starch (biobased)	1.5	Starch (biobased) (0.1 %)	5	33.93	3.28	1.47	9.66
Crete	Alb.	Starch (biobased)	1.8	Starch (biobased) (0.1 %)	5	30.19	1.98	0.89	6.57
Crete	No Alb.	Starch (biobased)	1.8	Starch (biobased) (0.1 %)	5	30.71	3.09	1.38	10.05
Crete	Alb.	Starch (biobased)	2	Starch (biobased) (0.1 %)	5	27.57	2.19	0.98	7.94
Crete	No Alb.	Starch (biobased)	2	Starch (biobased) (0.1 %)	5	28.27	3.15	1.41	11.14

Crete	Alb.	Starch (biobased)	2.5	Starch (biobased) (0.1 %)	5	22.39	2.40	1.07	10.73
Crete	No Alb.	Starch (biobased)	2.5	Starch (biobased) (0.1 %)	5	23.21	3.08	1.38	13.26
Crete	Alb.	Starch (biobased)	4.2	Starch (biobased) (0.1 %)	5	13.90	3.21	1.44	23.12
Crete	No Alb.	Starch (biobased)	4.2	Starch (biobased) (0.1 %)	5	16.25	2.41	1.08	14.80
Dijon	Alb.	Control (0 %)	1	Control (0 %)	1	42.39	NA	NA	NA
Dijon	No Alb.	Control (0 %)	1	Control (0 %)	2	42.97	1.70	1.20	3.95
Dijon	Alb.	Control (0 %)	1.5	Control (0 %)	5	39.61	1.65	0.74	4.17
Dijon	No Alb.	Control (0 %)	1.5	Control (0 %)	4	39.91	1.66	0.83	4.16
Dijon	Alb.	Control (0 %)	1.8	Control (0 %)	5	38.36	1.78	0.79	4.63
Dijon	No Alb.	Control (0 %)	1.8	Control (0 %)	4	38.85	1.72	0.86	4.42
Dijon	Alb.	Control (0 %)	2	Control (0 %)	5	37.59	1.80	0.80	4.78
Dijon	No Alb.	Control (0 %)	2	Control (0 %)	4	38.04	1.78	0.89	4.68
Dijon	Alb.	Control (0 %)	2.5	Control (0 %)	5	35.04	1.50	0.67	4.27
Dijon	No Alb.	Control (0 %)	2.5	Control (0 %)	4	35.59	1.94	0.97	5.46
Dijon	Alb.	Control (0 %)	4.2	Control (0 %)	5	24.88	1.53	0.69	6.16
Dijon	No Alb.	Control (0 %)	4.2	Control (0 %)	4	26.99	1.77	0.88	6.55
Dijon	Alb.	LDPE (conv.)	1	LDPE (conv.) (0.1 %)	4	43.19	0.86	0.43	2.00
Dijon	No Alb.	LDPE (conv.)	1	LDPE (conv.) (0.1 %)	1	38.21	NA	NA	NA
Dijon	Alb.	LDPE (conv.)	1.5	LDPE (conv.) (0.1 %)	5	40.43	1.14	0.51	2.82
Dijon	No Alb.	LDPE (conv.)	1.5	LDPE (conv.) (0.1 %)	3	41.74	5.64	3.26	13.51
Dijon	Alb.	LDPE (conv.)	1.8	LDPE (conv.) (0.1 %)	5	39.15	1.31	0.58	3.34
Dijon	No Alb.	LDPE (conv.)	1.8	LDPE (conv.) (0.1 %)	3	40.26	5.52	3.19	13.71
Dijon	Alb.	LDPE (conv.)	2	LDPE (conv.) (0.1 %)	5	38.17	1.56	0.70	4.10
Dijon	No Alb.	LDPE (conv.)	2	LDPE (conv.) (0.1 %)	3	39.45	5.44	3.14	13.79
Dijon	Alb.	LDPE (conv.)	2.5	LDPE (conv.) (0.1 %)	5	35.47	1.86	0.83	5.24

Dijon	No Alb.	LDPE (conv.)	2.5	LDPE (conv.) (0.1 %)	3	37.16	4.95	2.86	13.32
Dijon	Alb.	LDPE (conv.)	4.2	LDPE (conv.) (0.1 %)	5	24.35	1.87	0.84	7.68
Dijon	No Alb.	LDPE (conv.)	4.2	LDPE (conv.) (0.1 %)	3	23.85	0.88	0.51	3.70
Dijon	Alb.	Starch (biobased)	1	Starch (biobased) (0.1 %)	2	39.75	0.06	0.04	0.16
Dijon	No Alb.	Starch (biobased)	1	Starch (biobased) (0.1 %)	2	44.16	3.51	2.48	7.94
Dijon	Alb.	Starch (biobased)	1.5	Starch (biobased) (0.1 %)	4	38.74	1.27	0.64	3.29
Dijon	No Alb.	Starch (biobased)	1.5	Starch (biobased) (0.1 %)	5	40.91	2.79	1.25	6.82
Dijon	Alb.	Starch (biobased)	1.8	Starch (biobased) (0.1 %)	4	37.59	1.27	0.64	3.39
Dijon	No Alb.	Starch (biobased)	1.8	Starch (biobased) (0.1 %)	5	39.77	2.97	1.33	7.47
Dijon	Alb.	Starch (biobased)	2	Starch (biobased) (0.1 %)	4	36.85	1.49	0.75	4.05
Dijon	No Alb.	Starch (biobased)	2	Starch (biobased) (0.1 %)	5	38.97	3.05	1.36	7.82
Dijon	Alb.	Starch (biobased)	2.5	Starch (biobased) (0.1 %)	4	34.42	1.88	0.94	5.47
Dijon	No Alb.	Starch (biobased)	2.5	Starch (biobased) (0.1 %)	5	36.59	3.37	1.51	9.20
Dijon	Alb.	Starch (biobased)	4.2	Starch (biobased) (0.1 %)	4	21.73	4.53	2.27	20.87
Dijon	No Alb.	Starch (biobased)	4.2	Starch (biobased) (0.1 %)	5	25.53	0.80	0.36	3.12
Wageningen	Alb.	Control (0 %)	1	Control (0 %)	2	42.31	2.06	1.46	4.86
Wageningen	No Alb.	Control (0 %)	1	Control (0 %)	1	46.89	NA	NA	NA
Wageningen	Alb.	Control (0 %)	1.5	Control (0 %)	5	37.17	3.01	1.34	8.09
Wageningen	No Alb.	Control (0 %)	1.5	Control (0 %)	3	37.18	1.85	1.07	4.97
Wageningen	Alb.	Control (0 %)	1.8	Control (0 %)	5	25.48	3.72	1.66	14.59

Wageningen	No Alb.	Control (0 %)	1.8	Control (0 %)	3	24.59	2.84	1.64	11.54
Wageningen	Alb.	Control (0 %)	2	Control (0 %)	4	21.32	4.07	2.04	19.10
Wageningen	No Alb.	Control (0 %)	2	Control (0 %)	3	19.78	2.23	1.29	11.25
Wageningen	Alb.	Control (0 %)	2.5	Control (0 %)	4	16.43	3.08	1.54	18.73
Wageningen	No Alb.	Control (0 %)	2.5	Control (0 %)	3	14.94	1.83	1.06	12.25
Wageningen	Alb.	Control (0 %)	4.2	Control (0 %)	5	5.61	0.54	0.24	9.59
Wageningen	No Alb.	Control (0 %)	4.2	Control (0 %)	3	4.30	0.53	0.30	12.29
Wageningen	Alb.	LDPE (conv.)	1	LDPE (conv.) (0.1 %)	3	44.39	1.61	0.93	3.63
Wageningen	No Alb.	LDPE (conv.)	1	LDPE (conv.) (0.1 %)	0	NaN	NA	NA	NA
Wageningen	Alb.	LDPE (conv.)	1.5	LDPE (conv.) (0.1 %)	5	36.92	1.64	0.73	4.45
Wageningen	No Alb.	LDPE (conv.)	1.5	LDPE (conv.) (0.1 %)	4	39.35	0.92	0.46	2.35
Wageningen	Alb.	LDPE (conv.)	1.8	LDPE (conv.) (0.1 %)	5	23.31	1.51	0.68	6.49
Wageningen	No Alb.	LDPE (conv.)	1.8	LDPE (conv.) (0.1 %)	4	23.52	0.77	0.39	3.28
Wageningen	Alb.	LDPE (conv.)	2	LDPE (conv.) (0.1 %)	5	18.88	1.50	0.67	7.97
Wageningen	No Alb.	LDPE (conv.)	2	LDPE (conv.) (0.1 %)	4	18.62	0.61	0.30	3.27
Wageningen	Alb.	LDPE (conv.)	2.5	LDPE (conv.) (0.1 %)	5	14.87	1.71	0.76	11.49
Wageningen	No Alb.	LDPE (conv.)	2.5	LDPE (conv.) (0.1 %)	4	14.00	0.52	0.26	3.70
Wageningen	Alb.	LDPE (conv.)	4.2	LDPE (conv.) (0.1 %)	5	5.21	0.55	0.25	10.54
Wageningen	No Alb.	LDPE (conv.)	4.2	LDPE (conv.) (0.1 %)	4	5.27	0.31	0.16	5.97
Wageningen	No Alb.	PBAT (biodeg.)	1	PBAT (biodeg.) (0.1 %)	1	40.91	NA	NA	NA
Wageningen	No Alb.	PBAT (biodeg.)	1.5	PBAT (biodeg.) (0.1 %)	5	36.55	1.59	0.71	4.34
Wageningen	No Alb.	PBAT (biodeg.)	1.8	PBAT (biodeg.) (0.1 %)	5	24.73	3.04	1.36	12.28
Wageningen	No Alb.	PBAT (biodeg.)	2	PBAT (biodeg.) (0.1 %)	5	20.06	1.67	0.75	8.33
Wageningen	No Alb.	PBAT (biodeg.)	2.5	PBAT (biodeg.) (0.1 %)	5	15.52	1.15	0.52	7.42

Wageningen	No Alb.	PBAT (biodeg.)	4.2	PBAT (biodeg.) (0.1 %)	5	5.93	0.71	0.32	11.97
Wageningen	Alb.	Starch (biobased)	1	Starch (biobased) (0.1 %)	0	NaN	NA	NA	NA
Wageningen	No Alb.	Starch (biobased)	1	Starch (biobased) (0.1 %)	2	42.89	1.67	1.18	3.89
Wageningen	Alb.	Starch (biobased)	1.5	Starch (biobased) (0.1 %)	5	36.75	2.44	1.09	6.65
Wageningen	No Alb.	Starch (biobased)	1.5	Starch (biobased) (0.1 %)	3	37.77	1.99	1.15	5.26
Wageningen	Alb.	Starch (biobased)	1.8	Starch (biobased) (0.1 %)	5	24.35	1.41	0.63	5.81
Wageningen	No Alb.	Starch (biobased)	1.8	Starch (biobased) (0.1 %)	3	24.51	2.05	1.19	8.38
Wageningen	Alb.	Starch (biobased)	2	Starch (biobased) (0.1 %)	5	20.17	1.77	0.79	8.77
Wageningen	No Alb.	Starch (biobased)	2	Starch (biobased) (0.1 %)	3	20.02	1.82	1.05	9.12
Wageningen	Alb.	Starch (biobased)	2.5	Starch (biobased) (0.1 %)	5	15.73	1.33	0.59	8.45
Wageningen	No Alb.	Starch (biobased)	2.5	Starch (biobased) (0.1 %)	3	15.51	1.38	0.80	8.92
Wageningen	Alb.	Starch (biobased)	4.2	Starch (biobased) (0.1 %)	5	5.44	0.17	0.08	3.12
Wageningen	No Alb.	Starch (biobased)	4.2	Starch (biobased) (0.1 %)	3	5.72	0.85	0.49	14.89

Table 4: Summary of the mean weight diameter (MWD) descriptive statistics, for soil aggregate stability across the three experimental locations (Crete, Dijon, and Wageningen), under different treatments with or without the veterinary pharmaceutical albendazole (Alb.). Each experimental site included a control (0% MP) and MP additions at 0.1% concentration, using LDPE (conventional), starch-based (biobased), and PBAT (biodegradable, Wageningen only). For each treatment combination, the number of replicates (n), mean (M), standard deviation (SD), standard error (SE), coefficient of variation (Cv, %), and assumed measurement resolution (width) are reported.

Location	Al. /No Alb.	MP type	MP concentration	n.	M	SD	SE	Cv (%)	width
Crete	Alb.	Control	Control (0 %)	5	0.55	0.04	0.02	6.41	0.06
Crete	No Alb.	Control	Control (0 %)	5	0.59	0.10	0.04	16.09	0.06
Crete	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	0.59	0.08	0.03	13.02	0.13
Crete	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	0.55	0.07	0.03	12.96	0.13
Crete	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	0.54	0.09	0.04	15.82	0.13
Crete	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	0.59	0.04	0.02	7.36	0.13
Dijon	Alb.	Control	Control (0 %)	5	0.83	0.07	0.03	8.33	0.06
Dijon	No Alb.	Control	Control (0 %)	5	0.76	0.01	0.01	1.60	0.06
Dijon	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	0.74	0.03	0.01	3.57	0.13
Dijon	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	0.77	0.06	0.03	7.54	0.13
Dijon	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	0.76	0.06	0.03	8.53	0.13
Dijon	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	0.77	0.05	0.02	6.99	0.13
Wageningen	Alb.	Control	Control (0 %)	5	0.73	0.05	0.02	6.78	0.06
Wageningen	No Alb.	Control	Control (0 %)	5	0.72	0.03	0.01	3.97	0.06
Wageningen	Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	0.74	0.01	0.00	0.94	0.13
Wageningen	No Alb.	LDPE (conv.)	LDPE (conv.) (0.1 %)	5	0.73	0.02	0.01	2.77	0.13
Wageningen	No Alb.	PBAT (biodeg.)	PBAT (biodeg.) (0.1 %)	5	0.72	0.05	0.02	7.15	0.13
Wageningen	Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	0.76	0.03	0.02	4.59	0.13
Wageningen	No Alb.	Starch (biobased)	Starch (biobased) (0.1 %)	5	0.75	0.04	0.02	5.77	0.13