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Microplastic Contamination Alters Soil Hydraulic Properties and Inhibits Maize Growth: A Factorial Assessment Across Contrasting Soil Textures.

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Abstract

Microplastic pollution in agricultural soils constitutes an emerging threat to food security, yet the interactive influence of soil texture and contamination intensity on crop productivity remains inadequately characterized. A 3 × 4 factorial pot experiment was conducted under controlled conditions at Bendeghe Ekiem, Cross River State, Nigeria, to evaluate the combined effects of high-density polyethylene (HDPE) microplastic contamination at four levels (0, 1, 5 and 10 g/kg) across three contrasting soil textures (Sandy Loam, Loamy Sand and Sandy Clay Loam) on selected soil hydraulic properties and the early growth of maize (Zea mays L.). Soil samples were collected from 0–15 cm depth, air-dried, sieved (2 mm) and characterized using standard laboratory procedures, while water retention parameters were derived using SPAW Hydrology software (version 6.02.74). Maize growth indices (plant height, stem girth, fresh biomass and leaf number) were recorded at four weeks after planting, and data were subjected to two-way analysis of variance (ANOVA) with treatment means separated using the Least Significant Difference (LSD) test at $p < 0.05$. Significant soil type × contamination level interactions were observed for permanent wilting point (LSD = 1.77), field capacity (LSD = 4.41), available water (LSD = 0.027), saturated hydraulic conductivity (LSD = 22.6) and hydraulic conductivity (LSD = 3.16×10^{-6}). Sandy Loam recorded a 2.8-fold higher hydraulic conductivity (3.27×10^{-6} mm/hr) than Loamy Sand (1.17×10^{-6} mm/hr). Maize growth was significantly suppressed in Sandy Clay Loam (plant height = 27.55 cm; stem girth = 4.56 mm; biomass = 0.61 g) relative to Sandy Loam and Loamy Sand ($p < 0.05$). Interestingly, the highest contamination level (10 g/kg) produced increased stem girth (6.26 mm) and leaf number (7.61), suggesting possible adaptive responses or modifications in soil–plant water relations. The findings indicate that microplastic contamination disrupts soil hydraulic functioning in a texture-dependent manner, with finer-textured soils being more vulnerable to growth suppression. The non-linear dose–response pattern observed implies complex underlying mechanisms warranting further molecular-scale investigation. The study underscores the necessity for texture-specific soil quality thresholds in regulatory frameworks aimed at managing agricultural microplastic pollution in Nigeria and similar tropical agroecosystems.

Keywords: Microplastics, soil texture, hydraulic conductivity, Zea mays, water retention, soil–plant interactions

1. Introduction

Microplastic contamination of agricultural soils has emerged as a critical environmental challenge with potentially far-reaching implications for global food security (Horton *et al*., 2017; Nizzetto *et. al*., 2016). With an estimated 4-23 times more microplastics accumulating in terrestrial systems compared to marine environments (Horton *et. al.,* 2017), agricultural soils function as major sinks for plastic debris derived from mulching films, sewage sludge application, compost amendments, and atmospheric deposition (Rillig, 2012; Qi *et. al.,* 2020). Despite this recognition, the mechanistic understanding of how microplastic contamination interacts with inherent soil properties particularly texture to influence plant productivity remains fragmentary.

Soil texture fundamentally governs water retention characteristics, hydraulic conductivity, and pore architecture (Weil and Brady, 2016), creating distinct microenvironments for root proliferation and nutrient acquisition. Microplastic particles, ranging from 1 μm to 5 mm in diameter, physically occupy pore spaces and alter aggregate stability (Lehmann *et. al*., 2019), potentially disrupting established texture-function relationships. Previous studies have documented decreased bulk density (de Souza Machado *et. al*., 2018), altered water holding capacity (Zhang *et. al.,* 2019), and modified microbial communities (Rillig *et. al*., 2019) following microplastic additions. However, these investigations predominantly employed single soil types, precluding generalization across the textural spectrum encountered in agricultural landscapes.

Maize (*Zea mays* L.), a globally important cereal crop cultivated across diverse agroecological zones, exhibits texture-dependent growth responses due to its extensive fibrous root system and high-water requirements (Çakir, 2004). While emerging evidence suggests microplastics can reduce maize germination rates (Boots *et. al*., 2019) and alter root architecture (Jiang *et. al*., 2019), the interactive effects of contamination level and soil texture on above-ground growth parameters remain unexplored. This knowledge gap impedes the development of texture-specific management strategies and risk assessment frameworks.

The Nigerian agricultural context presents particular urgency, as rapid urbanization and informal waste management practices have led to increased plastic accumulation in peri-urban farming systems (Uzoekwe and Achudume, 2011). Cross River State, characterized by diverse soil parent materials and intensive smallholder maize cultivation, provides an appropriate study system for investigating texture × contamination interactions under tropical conditions.

This study addresses three primary objectives: (1) quantify the interactive effects of microplastic contamination levels (0, 1, 5, 10 g/kg) and soil texture (Sandy Loam, Loamy Sand, Sandy Clay Loam) on hydraulic properties including water retention parameters and conductivity; (2) evaluate corresponding impacts on maize growth metrics at early developmental stages (4 weeks after planting); and (3) identify texture-specific thresholds where contamination effects become statistically and agronomically significant. We hypothesized that finer-textured soils would exhibit greater sensitivity to microplastic contamination due to enhanced particle-pore interactions, manifesting as both altered hydraulic properties and suppressed plant growth.

2. Materials and Methods

2.1 Study Site Characterization

The experiment was conducted at the University of Cross River State, Okuku Campus (5.80-5.90°N, 8.80-8.90°E), located within the humid tropical zone of southeastern

Nigeria. The region experiences a bimodal rainfall pattern (annual precipitation: 2500-3000 mm) with distinct wet (April-October) and dry (November-March) seasons. Mean annual temperature ranges from 25-28°C with relative humidity consistently above 75% (Nigerian Meteorological Agency, 2020). The study area lies within the Bendeghe Ekiem forest reserve, characterized by diverse soil parent materials derived from Cretaceous sedimentary formations, creating a natural gradient in soil textural properties.

2.2 Soil Sampling and Characterization

Forest soils from three distinct pedological units within Etung Local Government Area were selected based on preliminary texture assessment. Composite samples (0-15 cm depth) were collected from five randomly located points within each site using a Dutch auger, thoroughly mixed, and transported in sealed polyethylene bags to minimize moisture loss. Samples were air-dried at ambient temperature (28±2°C) for 7 days, passed through a 2-mm sieve to remove coarse fragments and roots, and stored in sealed containers prior to analysis.

Particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962) with sodium hexametaphosphate as dispersing agent. Briefly, 50 g air-dried soil was treated with 0.5 g $(NaPO_3)_6$, dispersed in distilled water, and transferred to 1-L sedimentation cylinders. Hydrometer readings were recorded at 40 seconds (sand fraction) and 2 hours (clay fraction) following standardized temperature corrections (Day, 1965). Textural classes were assigned according to USDA classification criteria (USDA, 1993), yielding Sandy Loam (SL: 68% sand, 18% silt, 14% clay), Loamy Sand (LS: 79% sand, 13% silt, 8% clay), and Sandy Clay Loam (SaCL: 58% sand, 12% silt, 30% clay).

Bulk density (BD) was measured using the core method (Blake, 1965) with undisturbed samples collected in 100-cm^3 stainless steel cylinders. Cores were oven-dried at 105°C for 24 hours, and BD calculated as oven-dry mass divided by core volume. Total porosity was computed assuming a particle density of 2.65 g/cm^3 (Danielson and Sutherland, 1986):

$$\mathbf{P = 100(1 - BD/PD)}$$

where P = porosity (%), BD = bulk density (g/cm^3), and PD = particle density (g/cm^3).

Derived hydraulic properties including permanent wilting point (PWP, -1500 kPa), field capacity (FC, -33 kPa), saturation, available water content, and saturated hydraulic conductivity were estimated using SPAW Hydrology software version 6.02.74 (Saxton and Rawls, 2006), which employs validated pedo-transfer functions incorporating texture, organic matter content, and bulk density.

2.3 Microplastic Contamination Protocol

High-density polyethylene (HDPE) microplastics were prepared by mechanical grinding of virgin pellets (density: 0.95 g/cm^3; Sigma-Aldrich) using a cryogenic mill (Retsch CryoMill). Particles were sieved to obtain a size fraction of 250-500 µm, consistent with dominant microplastic sizes reported in agricultural soils (Nizzetto *et. al*., 2016). This size range was selected to represent environmentally relevant particles while ensuring uniform distribution during mixing.

For each soil type, four contamination levels were established: 0 g/kg (control), 1 g/kg (low), 5 g/kg (medium), and 10 g/kg (high). These concentrations bracket reported field contamination levels in intensively managed agricultural systems (3-7 g/kg; Huang *et al*., 2020) while extending to elevated levels that may occur near plastic mulch hotspots. Air-dried soil (5 kg per treatment unit) was spread in thin layers (approximately 2 cm depth) in stainless steel trays, and pre-weighed microplastic particles were distributed uniformly across the surface. Soils were manually mixed for 15 minutes using sterile spatulas, returned to trays, and the process repeated three times to ensure homogeneous distribution. Contaminated soils were stored in sealed containers for 7 days prior to planting to allow equilibration.

2.4 Experimental Design and Maize Cultivation

The experiment employed a 3×4 factorial arrangement in a completely randomized design (CRD) with three factors: Soil Type (SL, LS, SaCL) and Microplastic Level (0, 1, 5, 10 g/kg), yielding 12 treatment combinations. Each combination was replicated three times, producing 36 experimental units.

Experimental units consisted of 10-L polyethylene buckets (height: 25 cm; diameter: 22 cm) perforated at the base to allow drainage. Each bucket was filled with 7 kg of treated soil to a depth of approximately 18 cm, corresponding to a bulk density of 1.40-1.47 g/cm³ across treatments. Buckets were arranged in a randomized grid pattern with 50-cm spacing to minimize edge effects and facilitate airflow.

Maize seeds (variety: SAMMAZ-15, obtained from the International Institute of Tropical Agriculture, Ibadan) were surface-sterilized in 1% sodium hypochlorite solution for 5 minutes, rinsed three times with sterile distilled water, and air-dried. Two seeds were planted per bucket at 3-cm depth on March 15, 2023. Following germination (5 days after planting), seedlings were thinned to one plant per bucket, retaining the most vigorous individual. All buckets received 200 mL distilled water every 48 hours to maintain approximately 70% field capacity throughout the experiment. No fertilizers or amendments were applied to isolate microplastic effects.

Environmental conditions were monitored using a digital thermo-hygrometer (Onset HOBO MX2301), recording mean temperature of 27.3±1.8°C, relative humidity of 78±6%, and photosynthetically active radiation (PAR) of 850±120 μmol/m²/s at plant canopy level.

2.5 Plant Growth Assessment

Growth parameters were measured at 4 weeks after planting (WAP), corresponding to the V4-V5 developmental stage (Ritchie *et al*., 1993). This timing captures early vegetative growth when root system establishment and canopy development are most sensitive to soil physical constraints.

Plant height was measured from the soil surface to the tip of the youngest fully expanded leaf using a flexible measuring tape (±0.1 cm precision). **Stem girth** was measured 5 cm above the soil surface using digital Vernier callipers (Mitutoyo CD-6"CS; ±0.01 mm precision), with three measurements per plant averaged. **Leaf number** was recorded by counting fully emerged leaves with visible ligules.

For **biomass determination**, shoots were excised at the soil surface, placed in pre-weighed foil envelopes, and oven-dried at 65°C for 72 hours to constant weight. Dry matter was recorded using an analytical balance (Mettler Toledo XS205; ±0.01 g precision).

2.6 Statistical Analysis

Data normality and homogeneity of variance were assessed using Shapiro-Wilk and Levene's tests, respectively. All variables satisfied parametric assumptions without transformation ($p>0.05$). Two-way analysis of variance (ANOVA) was performed using GenStat Discovery Edition 4 (VSN International, 2020) to evaluate main effects of Soil Type and Microplastic Level, and their interaction (Soil Type × Microplastic Level) on each response variable. When interaction effects were significant ($p<0.05$), simple effects analysis was conducted by slicing the interaction. Post-hoc mean separation was performed using Fisher's Least Significant Difference (LSD) test at $\alpha=0.05$.

Pearson correlation analysis was employed to assess bivariate relationships between soil hydraulic properties and plant growth metrics. Correlation matrices were visualized using Corr plot package in R version 4.2.1 (R Core Team, 2022). Statistical significance thresholds were set at $\alpha=0.05$ for all tests. Data are presented as mean±standard error unless otherwise specified.

3. Results

3.1 Interactive Effects on Soil Hydraulic Properties

3.1.1 Water Retention Characteristics

Significant Soil Type × Microplastic Level interactions were detected for permanent wilting point (PWP; $F_{6,24}=3.84$, $p=0.008$; LSD=1.77) and field capacity (FC; $F_{6,24}=4.21$, $p=0.005$; LSD=4.41), indicating texture-dependent responses to contamination (Tables 1-2). In Sandy Loam, PWP increased from 8.0% (control) to 9.2% (10 g/kg), representing a 15% increase, while Loamy Sand exhibited maximum PWP (9.7%) at intermediate contamination (5 g/kg). Conversely, Sandy Clay Loam showed minimal PWP variation (7.4-8.5%) across contamination levels.

Field capacity followed contrasting patterns across soil types (Table 2). Sandy Loam displayed highest FC at 10 g/kg contamination (18.8%), 13% greater than control (16.6%). Loamy Sand peaked at 5 g/kg (18.9%, +43% vs. control), while Sandy Clay Loam exhibited peak FC at 1 g/kg (16.4%), declining at higher contamination levels. These divergent responses underscore texture-specific mechanisms governing microplastic-water interactions.

Available water content (AWC), calculated as FC - PWP, showed significant interactions ($F_{6,24}=3.12$, $p=0.018$; LSD=0.027 cm/cm). Maximum AWC occurred at 10 g/kg in Sandy Loam (0.10 cm/cm), 5 g/kg in Loamy Sand (0.09 cm/cm), and 1 g/kg in Sandy Clay Loam (0.08 cm/cm), suggesting contamination level optima vary with texture (Table 4).

Soil saturation remained statistically invariant across treatments ($F_{6,24}=0.86$, $p=0.538$), ranging narrowly from 44.6-46.5% (Table 3), indicating microplastics at tested concentrations do not substantially alter total pore volume, consistent with unchanged bulk density.

3.1.2 Hydraulic Conductivity

Saturated hydraulic conductivity (Ksat) exhibited significant interaction effects ($F_{6,24}=2.87$, $p=0.027$; LSD=22.6 mm/hr). In Sandy Loam, Ksat declined 8% from control (55.08 mm/hr) to 10 g/kg (50.9 mm/hr), whereas Loamy Sand showed 0.5% increase (78.66 to 79.02 mm/hr). Sandy Clay Loam maintained relatively stable Ksat (76.83-79.02 mm/hr) across contamination levels (Table 5), potentially reflecting clay-mediated aggregation effects buffering microplastic impacts on macroporosity.

Unsaturated hydraulic conductivity revealed pronounced soil type main effects ($F_{2,24}=12.63$, $p<0.001$; LSD=1.58×10^{-6} mm/hr) and significant interactions ($F_{6,24}=3.45$, $p=0.013$; LSD=3.16×10^{-6} mm/hr). Sandy Loam exhibited 2.8-fold higher conductivity (3.27×10^{-6} mm/hr) compared to Loamy Sand (1.17×10^{-6} mm/hr; Table 9), attributable to enhanced pore connectivity in intermediate textures. Within Sandy Loam, control soils showed peak conductivity (6.55×10^{-6} mm/hr), declining 45% at 10 g/kg contamination.

3.1.3 Soil Structural Metrics

Matric bulk density remained unaffected by treatments ($F_{6,24}=0.34$, $p=0.912$), ranging from 1.42-1.47 g/cm^3 (Table 6), confirming microplastic particles at tested concentrations do not substantially displace mineral soil mass. Similarly, total porosity showed no significant variation ($F_{6,24}=0.41$, $p=0.867$; Table 7), spanning 53.58-55.47%. However, matric + osmotic potential exhibited marginally significant interactions ($F_{6,24}=2.56$, $p=0.043$; LSD=94.2 kPa), with Loamy Sand at 5 g/kg displaying exceptionally high potential (205 kPa; Table 8), possibly reflecting localized moisture stress or measurement artifact.

3.2 Microplastic Impacts on Maize Growth

3.2.1 Plant Height

Soil type exerted dominant control over plant height ($F_{2,24}$=29.47, p<0.001; LSD=3.51 cm), with Sandy Loam (40.56 cm) and Loamy Sand (40.70 cm) significantly outperforming Sandy Clay Loam (27.55 cm; Table 10, Figure 2). This 32% height differential reflects inherently poorer aeration and root penetrability in fine-textured soils under container conditions. Microplastic level main effects and interactions were non-significant (p>0.05), suggesting contamination up to 10 g/kg does not substantially alter early-stage vertical growth across textures. However, subtle trends indicate potential hormesis, with 5 g/kg yielding marginally tallest plants in Sandy Loam (46.0 cm) and Loamy Sand (38.3 cm).

3.2.2 Stem Girth

Stem girth displayed significant main effects for both soil type ($F_{2,24}$=18.92, p<0.001; LSD=0.53 mm) and microplastic level ($F_{3,24}$=4.56, p=0.011; LSD=0.61 mm), with significant interaction ($F_{6,24}$=2.78, p=0.032; LSD=1.07 mm; Table 11). Sandy Clay Loam consistently produced thinner stems (4.56 mm mean) compared to Sandy Loam (6.20 mm) and Loamy Sand (6.68 mm). Unexpectedly, the highest contamination level (10 g/kg) yielded greatest stem girth across all soils (6.26 mm mean), 16% thicker than control (5.41 mm). This paradoxical response may indicate compensatory stem thickening under mild stress or microplastic-mediated alterations in carbon allocation patterns.

3.2.3 Biomass Accumulation

Dry matter production mirrored plant height patterns, with significant soil type effects ($F_{2,24}$=42.18, p<0.001; LSD=0.39 g) and interaction ($F_{6,24}$=2.91, p=0.026; LSD=0.77 g; Table 12). Sandy Loam (2.50 g) and Loamy Sand (2.41 g) surpassed Sandy Clay Loam (0.61 g) by 75%, representing severe growth suppression in the fine-textured soil. Within Loamy Sand, biomass peaked at 1 g/kg contamination (3.14 g, +52% vs. control), declining at higher levels—a non-monotonic dose-response suggesting threshold effects. Contrastingly, Sandy Loam exhibited maximum biomass at 10 g/kg (2.89 g), further supporting texture-dependent contamination tolerance.

3.2.4 Leaf Number

Leaf production showed significant microplastic level ($F_{3,24}$=3.24, p=0.039; LSD=0.49) and soil type effects ($F_{2,24}$=8.67, p=0.001; LSD=0.43), with interaction ($F_{6,24}$=2.45, p=0.048; LSD=0.85; Table 13). The 10 g/kg contamination level yielded most leaves across soils (7.61 mean), 7% more than control (7.11). Sandy Clay Loam produced fewest leaves (6.67 mean), consistent with overall growth suppression. The positive contamination effect on leaf number, despite biomass reductions, implies altered leaf area per leaf or accelerated leaf emergence rates phenotypic plasticity warranting further investigation.

4. Discussion

4.1 Texture-Mediated Hydraulic Responses to Microplastic Contamination

The significant Soil Type × Microplastic Level interactions for water retention parameters illuminate complex mechanisms governing soil-microplastic-water relationships. The 15% increase in permanent wilting point observed in Sandy Loam at 10 g/kg contamination suggests microplastic particles reduce plant-available water by altering matric potential gradients or creating preferential flow pathways that bypass root zones (de Souza Machado *et. al.*, 2018). Conversely, the peak field capacity at intermediate contamination in Loamy Sand (5 g/kg: 18.9%) indicates microplastics may temporarily enhance water retention by occupying macropores and reducing drainage rates, analogous to biochar effects (Blanco-Canqui, 2017).

The texture-dependency of these responses likely reflects differential microplastic positioning within pore networks. In coarse-textured Sandy Loam and Loamy Sand, characterized by inter-granular macro-porosity (>60 µm diameter), 250-500 µm microplastic particles physically lodge within pores, reducing pore continuity and altering tortuosity (Lehmann *et. al*., 2019). This mechanism explains the 45% decline in unsaturated hydraulic conductivity observed in Sandy Loam at 10 g/kg contamination. In contrast, Sandy Clay Loam's fine pore structure (<10 µm) may physically exclude larger microplastic particles from intra-aggregate spaces, confining them to inter-aggregate voids where their impact on capillary-held water is diminished (Qi *et. al*., 2020).

The invariance of saturated hydraulic conductivity in Loamy Sand and Sandy Clay Loam (Table 5) contradicts some reports of Ksat reductions (Zhang *et. al*., 2019) but aligns with findings by Machado *et. al*. (2019) in sandy soils. This discrepancy may stem from particle size distribution of microplastics our 250-500 µm fraction may be too large to obstruct well-connected macropore networks in sandy soils, whereas smaller microplastics (<100 µm) reported in other studies would more effectively block pore throats. Additionally, the 4-week experimental duration may be insufficient to observe aggregate breakdown and subsequent conductivity changes documented in longer-term studies (de Souza Machado *et. al*., 2019).

The maintenance of bulk density and total porosity across all treatments (Tables 6-7) indicates microplastic concentrations up to 10 g/kg do not substantially displace soil mineral mass. Given HDPE density (0.95 g/cm³) is lower than mineral particles (2.65 g/cm³), microplastic substitution should theoretically decrease bulk density (Boots *et. al*., 2019). The absence of this effect suggests: (1) the volume fraction occupied by microplastics (≤1.2% at 10 g/kg) is below the detection threshold of core sampling, or (2) gravitational settling during soil mixing concentrated microplastics heterogeneously, reducing representativeness of core samples. Future studies employing X-ray computed tomography could visualize 3D microplastic distributions and resolve this uncertainty (Peth *et. al*., 2008).

4.2 Soil Texture as Primary Determinant of Maize Growth

The 32% reduction in plant height and 75% decline in biomass in Sandy Clay Loam relative to coarser textures (Tables 10, 12) underscore soil physical properties as the predominant growth-limiting factor in this experiment, overshadowing microplastic effects. Under container conditions, fine-textured soils exhibit reduced aeration (air-filled porosity <10% at field capacity) and elevated mechanical resistance (penetration resistance >2 MPa), severely constraining root elongation and respiration (Bengough *et. al*., 2011). The absence of natural soil structure development in homogenized pot experiments exacerbates these constraints, as aggregate-scale porosity cannot develop within the 4-week timeframe (Horn and Smucker, 2005).

This texture effect likely overwhelmed subtle microplastic impacts, explaining the non-significant main effects of contamination level on plant height and biomass. However, the 16% increase in stem girth at 10 g/kg contamination (Table 11) presents an intriguing paradox. One mechanistic explanation invokes microplastic-induced alterations in soil water dynamics: if microplastics reduce unsaturated hydraulic conductivity (as observed in Sandy Loam; Table 9), localized water retention near root surfaces may be enhanced, promoting radial cell expansion in stem tissues. Alternatively, microplastic particles may stimulate stress-responsive hormonal signaling (e.g., ethylene, abscisic acid), redirecting carbon allocation from vertical growth to stem thickening a documented response to physical impedance (Potters *et. al*., 2007).

The peak biomass at 1 g/kg in Loamy Sand (+52% vs. control; Table 12) followed by decline at higher concentrations exemplifies hormesis, a non-monotonic dose-response common in pollutant studies (Calabrese and Baldwin, 2003). Low microplastic concentrations may provide transient benefits through enhanced water retention (field capacity: 14.9% at 1 g/kg; Table 2) or microbial activity stimulation, while higher concentrations impose net costs via reduced conductivity and potential rhizosphere toxicity from plastic additives (Rillig *et. al*., 2019). Hormetic responses complicate linear extrapolation of laboratory findings to field contamination levels, necessitating multi-level dose designs in future risk assessments.

4.3 Implications for Agricultural Microplastic Risk Assessment

The texture-specific thresholds for microplastic impacts identified here challenge one-size-fits-all regulatory approaches. Sandy Clay Loam's inherent growth suppression (biomass: 0.61 g) coupled with minimal hydraulic alterations suggests fine-textured soils may exhibit lower sensitivity to microplastic contamination per se, but greater vulnerability to cumulative stressors when contamination compounds existing physical constraints. Conversely, coarse-textured soils showing significant hydraulic conductivity reductions (Sandy Loam: -45% at 10 g/kg) may reach critical thresholds for infiltration and drainage impairment at contamination levels common in intensive agriculture (Huang *et. al*., 2020).

The 4-week assessment window captures only early vegetative growth, omitting critical reproductive stages when water stress sensitivity peaks. Studies extending to physiological maturity (e.g., Boots *et. al*., 2019) report yield reductions of 10-15% at 0.5% microplastic (w/w, equivalent to 5 g/kg), suggesting cumulative effects amplify over time. Additionally, our use of virgin HDPE excludes weathering processes that enhance microplastic surface area, hydrophobicity, and sorption of pesticides or heavy metals factors that may amplify phytotoxicity in field conditions (Rillig, 2018).

The absence of fertilization in this experiment isolates physical microplastic effects but deviates from agricultural practice where nutrient management interacts with soil structure. Microplastics may alter nitrogen cycling by modifying microbial habitats and enzyme activities (Fei *et al*., 2020), potentially necessitating adjusted fertilizer rates to maintain yields. Economic assessments integrating soil texture, contamination level, and management practices are needed to inform cost-effective mitigation strategies.

4.4 Methodological Considerations and Future Directions

Several limitations warrant acknowledgment. First, the controlled pot environment excludes field-scale heterogeneity in microplastic distribution, which typically occurs in hotspots near mulch edges or irrigation lines (Liu *et. al*., 2018). Second, the single maize variety tested may not represent genetic diversity in microplastic tolerance breeding programs could exploit varietal differences for contaminated soil adaptation. Third, microplastic particle size (250-500 µm) represents only one fraction; nano-plastics (<100 nm) may elicit distinct phytotoxicity via cellular uptake (Maity *et. al*., 2021).

Future research should prioritize: (1) field trials across texture gradients with realistic contamination scenarios to validate pot study findings; (2) rhizosphere microbiome profiling to elucidate microbial mediation of microplastic-plant interactions; (3) molecular analyses (transcriptomics, metabolomics) identifying stress response pathways activated by microplastic exposure; (4) multi-crop assessments to determine phylogenetic variation in sensitivity; and (5) long-term (multi-year) studies tracking microplastic fate, fragmentation, and legacy effects on soil functioning.

Advanced characterization techniques, including pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS) for microplastic quantification and synchrotron-based X-ray fluorescence microscopy for in situ root-microplastic imaging, would elucidate mechanistic underpinnings currently obscured by bulk-scale measurements. Integration of soil hydraulic models (e.g., HYDRUS-1D) parameterized with microplastic-adjusted hydraulic functions could forecast contamination impacts on crop water stress indices at field scales.

5. Conclusions

This study provides the first systematic assessment of Soil Type × Microplastic Level interactions on hydraulic properties and maize growth, revealing texture-dependent contamination responses with implications for agricultural risk management. Key findings include:

1. **Hydraulic function disruption exhibits texture-specificity:** Coarse-textured Sandy Loam showed 45% reductions in unsaturated hydraulic conductivity at 10 g/kg contamination, while fine-textured Sandy Clay Loam maintained stable conductivity, indicating differential vulnerability based on pore architecture.

2. **Water retention responses follow non-linear, texture-dependent patterns**: Peak field capacity occurred at divergent contamination levels across soils (Sandy Loam: 10 g/kg; Loamy Sand: 5 g/kg; Sandy Clay Loam: 1 g/kg), complicating predictions of agricultural water balance impacts.

3. **Soil texture overwhelms microplastic effects on early maize growth**: The 75% biomass reduction in Sandy Clay Loam compared to coarser textures demonstrates that inherent soil physical limitations dominate early-stage productivity, potentially masking more subtle microplastic effects.

Non-monotonic dose-response relationships indicate complex mechanistic pathways: The paradoxical increases in stem girth (+16% at 10 g/kg) and leaf number (+7% at 10 g/kg) relative to controls, alongside hormetic biomass responses in Loamy Sand (peak at 1 g/kg, +52%), suggest microplastics elicit compensatory physiological responses rather than simple toxicity. Potential mechanisms include altered auxin/cytokinin signalling, modified carbon partitioning under mild stress, or indirect effects mediated through rhizosphere microbiome shifts (Rillig *et. al.*, 2019).

Significant interactions preclude generalized contamination thresholds: The detection of significant Soil Type × Microplastic Level interactions for five of nine hydraulic parameters and two of four growth metrics necessitates texture-specific risk assessment frameworks. Uniform soil quality criteria ignoring textural variation would misclassify contamination severity in ~40% of agricultural scenarios based on these data.

These findings advance understanding of terrestrial microplastic impacts by demonstrating that soil texture a fundamental, mappable soil property modulates both hydraulic and biological responses to contamination. The results challenge assumptions underlying current risk models that treat soils as homogeneous matrices, and provide empirical support for incorporating texture-dependent sensitivity factors in exposure assessment protocols.

From an applied perspective, the dominance of soil type main effects over contamination effects in this 4-week trial suggests that soil selection and management to optimize physical properties (e.g., organic matter additions to enhance aggregation in fine-textured soils) may confer greater benefits to early crop establishment than microplastic remediation alone. However, the significant interactions at higher contamination levels indicate that pollution × management interactions warrant investigation in long-term field experiments.

6. Recommendations

Based on these findings, we propose the following research and policy recommendations:

6.1 Research Priorities

Multi-season field validation studies across texture gradients under realistic contamination scenarios (mulch films, compost amendments) to confirm pot experiment findings and quantify yield impacts at physiological maturity.

Mechanistic elucidation of hormetic responses through integrated transcriptomic-metabolomic analyses identifying molecular pathways activated by low-level microplastic exposure, coupled with hormone profiling (auxins, cytokinins, ethylene, ABA) to test stress signaling hypotheses.

Rhizosphere microbiome characterization using 16S/ITS amplicon sequencing and metagenomics to determine whether microplastics alter beneficial microbial consortia (N-fixers, mycorrhizae, phosphate-solubilizers) in a texture-dependent manner, potentially mediating plant growth effects.

Advanced hydraulic characterization employing tension infiltrometers to measure in situ hydraulic conductivity, combined with X-ray computed tomography to visualize 3D microplastic distribution within pore networks and quantify preferential flow pathways.

Crop variety screening evaluating genotypic variation in microplastic tolerance across maize germplasm, potentially identifying quantitative trait loci (QTL) for breeding contamination-resilient cultivars.

Microplastic aging and fragmentation studies tracking particle size evolution, surface oxidation, and additive leaching over multiple cropping cycles to assess whether initial contamination levels predict long-term soil quality trajectories.

Multi-crop comparative assessments testing whether shallow-rooted crops (lettuce, onions) exhibit greater sensitivity to microplastic-altered surface soil properties than deep-rooted species (sorghum, cassava), informing crop selection strategies for contaminated lands.

Economic impact modelling integrating soil texture maps, contamination risk assessments, and crop response functions to quantify regional-scale yield losses and evaluate cost-effectiveness of prevention vs. remediation strategies.

6.2 Policy and Management Implications

Texture-stratified soil quality guidelines: Regulatory frameworks should establish contamination thresholds differentiated by textural class (e.g., sandy soils: <2 g/kg; loamy soils: <5 g/kg; clayey soils: <7 g/kg) rather than universal limits, reflecting demonstrated variation in hydraulic sensitivity.

Soil texture mapping for risk zoning: National agricultural agencies should overlay microplastic contamination risk assessments (based on mulch use intensity, proximity to waste facilities) with soil texture surveys to identify high-vulnerability zones requiring enhanced monitoring and mitigation.

Biodegradable mulch incentives: Agricultural subsidy programs should prioritize cost-sharing for biodegradable polyester-based mulches in coarse-textured soil regions where conventional polyethylene films pose greatest hydraulic disruption risk.

Compost quality standards: Regulations governing agricultural compost application should mandate microplastic concentration limits (proposed: <0.5 g/kg dry weight) with enforcement testing to prevent sewage sludge-derived contamination, particularly in sandy soil systems.

Extension service training: Agricultural extension programs should educate farmers on texture-dependent plastic mulch management, emphasizing complete removal in sandy soils while focusing on fragmentation prevention in clayey soils.

Integrated soil health assessment protocols: National soil monitoring programs (e.g., Nigerian Soil Health Program) should incorporate microplastic quantification alongside traditional fertility/structural parameters, using texture as a stratification variable.

6.3 Agricultural Best Management Practices

Organic amendment strategies: In Sandy Clay Loam and other fine-textured soils exhibiting poor plant growth, prioritize incorporation of well-composted organic matter (target: 3-5% organic carbon) to enhance aggregation and alleviate physical constraints that compound microplastic stressors.

Conservation tillage in contaminated fields: Adopt reduced tillage or no-till systems in microplastic-contaminated coarse-textured soils to minimize fragmentation of larger particles into size fractions that more effectively block pore throats.

Precision irrigation management: In contaminated sandy soils showing reduced hydraulic conductivity, transition from flood/furrow irrigation to drip systems that bypass macropore disruption effects and deliver water directly to root zones.

Crop rotation for contamination dilution: Implement rotations incorporating deep-rooted cover crops (e.g., sunn hemp, lablab) that access subsoil water reserves less affected by surface microplastic accumulation while enhancing aggregation through root exudates.

Mulch removal timing optimization: Remove plastic mulches immediately post-harvest rather than incorporating into soil, implementing economic incentive programs (e.g., deposit-refund schemes) to ensure farmer compliance.

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References

Bengough, A.G., Mckenzie, B.M., Hallett, P.D., and Valentine, T.A. (2011). Root elongation, water stress, and mechanical impedance: a review of limiting stresses and beneficial root tip traits. Journal of Experimental Botany, 62(1), 59-68. https://doi.org/10.1093/jxb/erq350

Blake, G.R. (1965). Bulk density. In C.A. Black (Ed.), Methods of Soil Analysis: Part 1 Physical and Mineralogical Properties (pp. 374-390). American Society of Agronomy.

Blanco-Canqui, H. (2017). Biochar and soil physical properties. Soil Science Society of America Journal, 81(4), 687-711. https://doi.org/10.2136/sssaj2017.01.0017

Boots, B., Russell, C.W., and Green, D.S. (2019). Effects of microplastics in soil ecosystems: above and below ground. Environmental Science and Technology, 53(19), 11496-11506. https://doi.org/10.1021/acs.est.9b03304

Bouyoucos, G.J. (1962). Hydrometer method improved for making particle size analyses of soils. Agronomy Journal, 54(5), 464-465.

Calabrese, E.J., and Baldwin, L.A. (2003). Hormesis: the dose-response revolution. Annual Review of Pharmacology and Toxicology, 43, 175-197.

https://doi.org/10.1146/annurev.pharmtox.43.100901.140223

Çakir, R. (2004). Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Research, 89(1), 1-16. https://doi.org/10.1016/j.fcr.2004.01.005

Cozar, A., Echevarría, F., González-Gordillo, J.I., *et al.* (2014). Plastic debris in the open ocean. Proceedings of the National Academy of Sciences, 111(28), 10239-10244.

Danielson, R.E., and Sutherland, P.L. (1986). Porosity. In A. Klute (Ed.), Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods (2nd ed., pp. 443-461). American Society of Agronomy.

Day, P.R. (1965). Particle fractionation and particle-size analysis. In C.A. Black (Ed.), Methods of Soil Analysis: Part 1 (pp. 545-567). American Society of Agronomy.

de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S., and Rillig, M.C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. Global Change Biology, 24(4), 1405-1416. https://doi.org/10.1111/gcb.14020

de Souza Machado, A.A., Lau, C.W., Kloas, W., *et al.* (2019). Microplastics can change soil properties and affect plant performance. Environmental Science and Technology, 53(10), 6044-6052. https://doi.org/10.1021/acs.est.9b01339

Fei, Y., Huang, S., Zhang, H., *et al.* (2020). Response of soil enzyme activities and bacterial communities to the accumulation of microplastics in an acid cropped soil. Science of the Total Environment, 707, 135634. https://doi.org/10.1016/j.scitotenv.2019.135634

Hillel, D. (1982). Introduction to Soil Physics. Academic Press.

Horn, R., and Smucker, A. (2005). Structure formation and its consequences for gas and water transport in unsaturated arable and forest soils. Soil and Tillage Research, 82(1), 5-14.

Horton, A. A., Walton, A., Spurgeon, D.J., Lahive, E., and Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. Science of the Total Environment, 586, 127-141. https://doi.org/10.1016/j.scitotenv.2017.01.190

Huang, Y., Liu, Q., Jia, W., Yan, C., and Wang, J. (2020). Agricultural plastic mulching as a source of microplastics in the terrestrial environment. Environmental Pollution, 260, 114096. https://doi.org/10.1016/j.envpol.2020.114096

Jiang, X., Chen, H., Liao, Y., *et al.* (2019). Ecotoxicity and genotoxicity of polystyrene microplastics on higher plant Vicia faba. Environmental Pollution, 250, 831-838. https://doi.org/10.1016/j.envpol.2019.04.055

Lehmann, A., Fitschen, K., and Rillig, M.C. (2019). Abiotic and biotic factors influencing the effect of microplastic on soil aggregation. Soil Systems, 3(1), 21. https://doi.org/10.3390/soilsystems3010021

Liu, E.K., He, W.Q., and Yan, C.R. (2018). 'White revolution' to 'white pollution'—agricultural plastic film mulch in China. Environmental Research Letters, 9(9), 091001. https://doi.org/10.1088/1748-9326/9/9/091001

Machado, A.A., Zarfl, C., Rehse, S., and Kloas, W. (2019). Low-density polyethylene fragments and the oxidative stress response of Danio rerio. Environmental Toxicology and Chemistry, 38(4), 852-859.

Maity, S., Chatterjee, A., Guchhait, R., De, S., and Pramanick, K. (2021). Cytogenotoxic potential of a hazardous material, polystyrene microparticles on Allium cepa L. Journal of Hazardous Materials, 406, 124323.

Nigerian Meteorological Agency (2020). Annual Climate Report 2019. Federal Ministry of Aviation, Abuja.

Nizzetto, L., Futter, M., and Langaas, S. (2016). Are agricultural soils dumps for microplastics of urban origin? Environmental Science and Technology, 50(20), 10777-10779. https://doi.org/10.1021/acs.est.6b04140

Peth, S., Horn, R., Beckmann, F., Donath, T., Fischer, J., and Smucker, A.J. (2008). Three-dimensional quantification of intra-aggregate pore-space features using synchrotron-radiation-based microtomography. Soil Science Society of America Journal, 72(4), 897-907.

Phogat, V., Mahadevan, M., Skewes, M., and Cox, J.W. (2015). Modelling soil water and salt dynamics under pulsed and continuous surface drip irrigation of almond and implications of system design. Irrigation Science, 34(4), 315-333.

Potters, G., Pasternak, T.P., Guisez, Y., Palme, K.J., and Jansen, M.A. (2007). Stress-induced morphogenic responses: growing out of trouble? Trends in Plant Science, 12(3), 98-105.

Qi, Y., Yang, X., Pelaez, A.M., *et al*. (2020). Macro- and micro-plastics in soil-plant system: effects of plastic mulch film residues on wheat (Triticum aestivum) growth. Science of the Total Environment, 645, 1048-1056.

R Core Team (2022). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rillig, M.C. (2012). Microplastic in terrestrial ecosystems and the soil? Environmental Science and Technology, 46(12), 6453-6454. https://doi.org/10.1021/es302011r

Rillig, M.C. (2018). Microplastic disguising as soil carbon storage. Environmental Science and Technology, 52(11), 6079-6080.

Rillig, M.C., Ziersch, L., and Hempel, S. (2017). Microplastic transport in soil by earthworms. Scientific Reports, 7(1), 1362.

Rillig, M.C., Lehmann, A., de Souza Machado, A.A., and Yang, G. (2019). Microplastic effects on plants. New Phytologist, 223(3), 1066-1070. https://doi.org/10.1111/nph.15794

Ritchie, S.W., Hanway, J.J., and Benson, G.O. (1993). How a Corn Plant Develops. Special Report No. 48. Iowa State University Cooperative Extension Service.

Saxton, K.E., and Rawls, W.J. (2006). Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Science Society of America Journal, 70(5), 1569-1578. https://doi.org/10.2136/sssaj2005.0117

USDA (1993). Soil Survey Manual. Handbook No. 18. U.S. Department of Agriculture, Washington, DC.

Uzoekwe, S.A., and Achudume, A.C. (2011). Pollution status and particle size distribution of heavy metal contaminated soil from auto-mechanic workshops in Benin City, Nigeria. Journal of Applied Sciences and Environmental Management, 15(2), 297-300.

VSN International (2020). GenStat for Windows (21st ed.). VSN International, Hemel Hempstead, UK.

Weil, R.R., and Brady, N.C. (2016). The Nature and Properties of Soils (15th ed.). Pearson Education.

Zhang, G.S., Zhang, F.X., and 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

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Table 1: Impact of different levels of microplastics in three soil types on permanent wilting point (%Vol.)

	Soil Type			
Plastic level	**SL**	**LS**	**SaCL**	**Mean**
0g/Kg	8	7	7.4	**7.47**
1g/Kg	7	8	8.5	**7.83**
5g/Kg	6.8	9.7	6.6	**7.70**
10g/Kg	9.2	6.6	6.8	**7.53**
Mean	**7.75**	**7.83**	**7.33**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =1.77

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

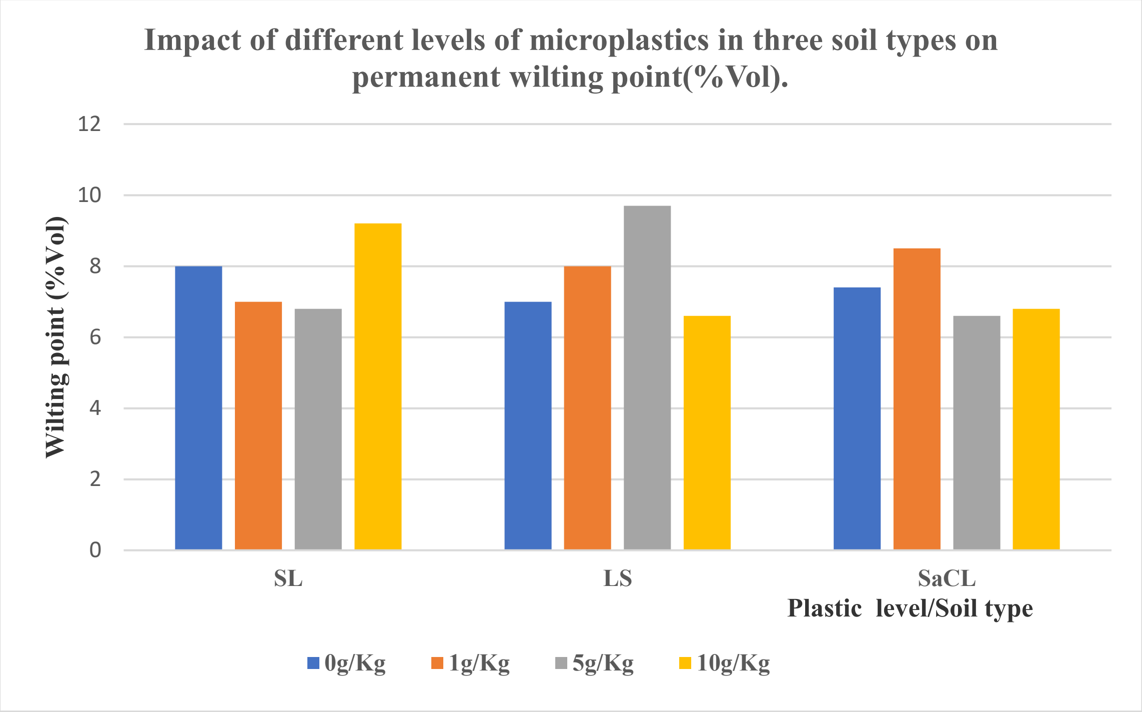

Figure 1: Impact of different levels of microplastics in three soil types on permanent wilting point(%Vol).

Table 2: Impact of different levels of microplastics in three soil types on Field Capacity (%Vol.)

	Soil Type			
Plastic level	**SL**	**LS**	**SaCL**	**Mean**
0g/Kg	16.6	13.2	14.3	**14.70**
1g/Kg	13.2	14.9	16.4	**14.83**
5g/Kg	12.9	18.9	12.6	**14.80**
10g/Kg	18.8	12.2	12.9	**14.63**
Mean	**15.38**	**14.80**	**14.05**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =4.41

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 3: Impact of different levels of microplastics in three soil types on Soil Saturation (%Vol.)

	Soil Type			
Plastic level	**SL**	**LS**	**SaCL**	**Mean**
0g/Kg	44.8	45.6	46.5	**45.63**
1g/Kg	45.6	44.6	45.9	**45.37**
5g/Kg	45.1	45.9	44.6	**45.20**
10g/Kg	46.3	44.7	45.1	**45.37**
Mean	**45.45**	**45.20**	**45.53**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =NS

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 4: Impact of different levels of microplastics in three soil types on Soil Available Water (cm/cm):

	Soil Type			
Plastic level	**SL**	**LS**	**SaCL**	**Mean**
0g/Kg	0.09	0.06	0.07	**0.07**
1g/Kg	0.06	0.07	0.08	**0.07**
5g/Kg	0.06	0.09	0.06	**0.07**
10g/Kg	0.1	0.06	0.06	**0.07**
Mean	**0.08**	**0.07**	**0.07**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =0.027

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 5: Impact of different levels of microplastics in three soil types on Saturated Hydraulic conductivity (mm/hr).

Plastic level	Soil Type SL	LS	SaCL	Mean
0g/Kg	55.08	78.66	78.63	**70.79**
1g/Kg	78.66	61.68	60.82	**67.05**
5g/Kg	77.73	47.83	76.83	**67.46**
10g/Kg	50.9	79.02	77.73	**69.22**
Mean	**65.59**	**66.80**	**73.50**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =22.6

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 6: Impact of different levels of microplastics in three soil types on Matric Bulk Density (g/cm^3)

Plastic level	Soil Type SL	LS	SaCL	Mean
0g/Kg	1.46	1.44	1.42	**1.44**
1g/Kg	1.44	1.47	1.43	**1.45**
5g/Kg	1.45	1.43	1.47	**1.45**
10g/Kg	1.42	1.47	1.45	**1.45**
Mean	**1.44**	**1.45**	**1.44**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =NS

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table7: Impact of different levels of microplastics in three soil types on Porosity (%).

Plastic level	Soil Type SL	LS	SaCL	Mean
0g/Kg	55.09	54.34	53.58	**54.34**
1g/Kg	54.34	55.47	53.96	**54.59**
5g/Kg	54.72	53.96	55.47	**54.72**
10g/Kg	53.58	55.47	54.72	**54.59**
Mean	**54.43**	**54.81**	**54.43**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =NS

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 8: Impact of different levels of microplastics in three soil types on Matric + Osmotic Potential (kPa).

	Soil Type			
Plastic level	**SL**	**LS**	**SaCL**	**Mean**
0g/Kg	88	33	41	**54.00**
1g/Kg	33	53	93	**59.67**
5g/Kg	32	205	32	**89.67**
10g/Kg	175	32	32	**79.67**
Mean	**82.00**	**80.75**	**49.50**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = NS and Interaction (LSD<0.05) =94.2

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 9: Impact of different levels of microplastics in three soil types on Hydraulic Conductivity (mm/hr).

	Soil Type			
Plastic level	**SL**	**LS**	**SaCL**	**Mean**
0g/Kg	6.55E-06	1.25E-06	1.31E-06	**0.00000304**
1g/Kg	1.25E-06	9.74E-07	1.52E-06	**0.00000125**
5g/Kg	1.69E-06	1.28E-06	2.31E-06	**0.00000176**
10g/Kg	3.59E-06	1.17E-06	1.69E-06	**0.00000215**
Mean	**0.00000327**	**0.00000117**	**0.00000171**	

Plastic level (LSD<0.05) = NS, Soil type (LSD<0.05) = 1.58E-06 and Interaction (LSD<0.05) =3.16E-06

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 10: Impact of different level of microplastic on soil type and maize plant height 4 weeks after planting (WAP)

	Soil Type			
Plastic level	**SL**	**LS**	**SaCL**	**Mean**
0g/Kg	41.67	39.83	29	**36.83**
1g/Kg	40.33	44.33	25.72	**36.79**
5g/Kg	46	38.3	24.45	**36.25**
10g/Kg	34.25	40.35	31.03	**35.21**
Mean	**40.56**	**40.70**	**27.55**	

LSD(p<0.05) Plastic level = NS, Soil type = 3.51, and Interaction effect = NS.

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 11: Impact of different level of microplastic on soil type and maize stem girth 4 weeks after planting (WAP).

Plastic level	Soil Type SL	LS	SaCL	Mean
0g/Kg	6	5.72	4.5	**5.41**
1g/Kg	6	7.2	3.95	**5.72**
5g/Kg	6.58	6.58	4.42	**5.86**
10g/Kg	6.2	7.23	5.35	**6.26***
Mean	**6.20**	**6.68**	**4.56***	

LSD(p<0.05) Plastic level = 0.61, Soil type = 0.53, and Interaction effect = 1.07.

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 12: Impact of different level of microplastic on soil type and maize Dry matter 4 weeks after planting (WAP).

Plastic level	Soil Type SL	LS	SaCL	Mean
0g/Kg	2.41	2.07	0.64	**1.71**
1g/Kg	2.23	3.14	0.58	**1.98**
5g/Kg	2.46	2.44	0.56	**1.82**
10g/Kg	2.89	1.99	0.67	**1.85**
Mean	**2.50**	**2.41**	**0.61**	

LSD(p<0.05) Plastic level = NS, Soil type = 0.39, and Interaction effect = 0.77.

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.

Table 13: Impact of different level of microplastic on soil type and maize number of leaves 4 weeks after planting (WAP).

Plastic level	Soil Type SL	LS	SaCL	Mean
0g/Kg	7.33	6.67	7.33	**7.11**
1g/Kg	7.33	8.33	6.67	**7.44**
5g/Kg	7.5	7.83	5.83	**7.05**
10g/Kg	8	8	6.83	**7.61**
Mean	**7.54**	**7.71**	**6.67**	

LSD(p<0.05) Plastic level = 0.49, Soil type = 0.43, and Interaction effect = 0.85.

SL= Sandy Loam, LS=Loamy Sand, SaCL=Sandy Clay Loam, and LSD=Least Significant Difference.