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Effect of Temperature on Microplastic Degradation in Soil Environment

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Abstract

The contamination of soil caused by the degradation of plastics introduced through disposal has been increasing globally. Researchers have reported that exposure to microplastics, the degradative product of plastic materials triggers a "wide variety of toxic insults". The present study aimed at investigating the effect of temperature on microplastic degradation in soil environment. Soil samples were collected from Federal University Wukari

farm, air-dried and sieved to obtain fine particles. They were arranged in three groups; one served as the control (Group 1), containing no shredded microplastics, whereas microplastics were shredded in Group 2 and Group 3 soil samples. They were all arranged in triplicates. The control group was kept at room temperature for 14 days whereas Group 2 was exposed to sunlight for 14 days. Group 3 was exposed to sunlight for 7 days. The results obtained from this study revealed the presence of the following microplastic types in Group 2 and 3 soil samples: polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol, terephthatic acid, acrylic acid and polyester. The highest level of total detectable microplastics were associated with Group 3 soil samples (59314.95±808.35), followed by Group 2 soil samples (56022±1352.14) and lastly Group 1 (control) soil samples (32703.51±649.99) respectively. The result also revealed polyamide to be the most abundant microplastic present in all the assayed soil samples: Group 3 (48977.99±1071.61), Group 2 (52204.46±582.03) and Group 1 (28022.08±425.28) whereas the least microplastic present in all assayed soil samples was Terephthatic acid shown as thus: Group 3 (393.69±17.44) > Group 2 (369.36±28.11) > Group 3 (211.32±14.77) respectively. Overall, the result revealed that soil samples exposed to sunlight for a period of 7 days (Group 3) had the highest level of individually detected microplastics followed by soil samples exposed to sunlight for 14 days (Group 2). The control group clearly showed the least levels of individually detected microplastics. The study revealed that microplastics upon exposure to UV rays from sun light could undergo degradation yielding several intermediates which may be either more or less harmful. The study also revealed that the longer the exposure of a microplastic material to UV rays, the higher the degradation rate and the more intermediates associated with the microplastic material will be yielded. On the other hand, the shorter the exposure time of a microplastic material to UV rays, the lesser the degradation rate and less intermediates associated with the microplastic material will be yielded.

Keywords: Temperature, Microplastic, Exposure, Soil, Environment and Degradation

INTRODUCTION

Large amounts of plastics have been produced worldwide due to the widespread use of plastics materials in our daily life (Geyer *et al.,* 2017, Otitoju *et al.,* 2021), to the point that plastics are now becoming an important threat to both terrestrial and aquatic systems (Bläsing and Amelung, 2018). Microplastics are plastic particles smaller than 5 mm, and their effects on soil systems, have received increasing attention in recent years (Mai *et al.,*

2018). When these materials are left exposed in the environment, they can undergo any of the following: thermal degradation, microbial degradation, photodegradation, chemical degradation, among others. On the basis of microplastic toxicity, certain microplastics have been reported to undergo degradation when left exposed in the environment, yielding harmful intermediates which could pose threat to soil organisms, plants and animals. Other microplastics can be degraded to yield intermediates that could be used up by microbes as carbon source. After microplastics may have undergone degradation, they may occur in many shapes, exhibiting a variety of physical and chemical properties (Rillig and Lehmann, 2020). The accumulation of microplastics in soil may impact soil characteristics (Liu *et al.,* 2017; Yi *et al.,* 2020), depending on microplastic properties (Lozano *et al.,* 2021a). Indeed, microplastic shape may determine how microplastics interact with soil particles (Rillig and Lehmann 2020). For instance, fibers due to their linear shape may destabilize soil structure once they are incorporated into soil aggregates (de Souza Machado *et al.,* 2018).

Microplastics pollute terrestrial systems through variety of pathways including soil amendments, mulching, sludge, irrigation, flooding, atmospheric input and littering or street runoff (Mai *et al.,* 2018; Boots *et al.,* 2019). Microplastics could alter soil microbial communities (Yi *et al.,* 2020), affecting enzymatic activities (Hargreaves and Hofmockel, 2014). Recent research has shown that microplastics could affect nutrient and/or substrate availability (Lozano *et al.,* 2021b), likely due to microplastic absorption or its competition for physicochemical niches with microorganisms (Yu *et al.,* 2020). Polyethylene (PE) and polyvinyl chloride (PVC) microplastics could enhance enzymes such as urease and acid phosphatase (Fei *et al.,* 2020) while polypropylene (PP), polyether sulfone (PES) and polyvinyl chloride (PVC) could inhibit or enhance soil fluorescein diacetate hydrolase activity, respectively (Liang *et al.,* 2019; Fei *et al.,* 2020), depending on the polymer type. Likewise, enzymes such as β-D-glucosidase and cellobiosidase (involved in cellulose degradation), N-acetylβ-glucosaminidase (involved in chitin degradation), and phosphatase which are related to C, N, P-cycling, could be negatively affected by microplastics (Liang *et al.,* 2021).

Research suggests that higher temperatures can accelerate the degradation of microplastics in soil environments. Temperature influences chemical reactions and microbial activity, both of which can affect the breakdown of microplastics. Studies have also shown that temperature can induce changes in the chemical composition of microplastics. Higher temperatures may lead to alterations in the molecular structure of microplastics, affecting

their degradation pathways. (Huerta *et al.,* 2019). Elevated temperatures may shorten the residence time of microplastics in soil environments, potentially reducing their long-term impact (Wang *et al.,* 2020). Understanding the temperature effect is crucial for assessing the environmental persistence of microplastics. Hence, the need for this research.

MATERIALS AND METHODS

Study Area

This study was conducted in Federal University Wukari farm, Taraba State, Nigeria. Wukari is a famous city located formerly in Gongola State of Nigeria Wukari is located at latitude $7^{0}51$ North and longitude $9^{0}47$ East with an average elevation of 155 (masl). Wukari lies between Taraba State and Benue State and it is an agricultural center. It is bounded in the south by Benue state, north by Gassol LGA, east by Donga LGA and west by Ibi LGA. Wukari covers an area of 4,308 km^2 and with a population of about 241,546 at the 2006 census, a traditional state rich with various cultures, norms and value. Fishing, farming and trading are the major occupation of the people.

Experimental Design

To investigate the effect of temperature on microplastic degradation in soil environment, the experimental design in table 1 below was drafted. Three groups of soil samples were drafted. Group 1 served as the control, containing no shredded microplastics, whereas microplastics were shredded in Group 2 and Group 3 soil samples. They were all arranged in triplicates. The control group was kept at room temperature for 14 days whereas Group 2 was exposed to sunlight for 14 days. Group 3 was exposed to sunlight for 7 days. Group 2 and 3 served as treatment groups, receiving unpolluted soil, and shredded microplastics in the ratio 80:20 and 80:20 respectively. While the control group received 100% unpolluted soil only

Table 1. Research experimental design

Group	Sample Mix	Period of Exposure to Sunlight
Group 1	100% soil +0% shredded microplastics	14 days (at room temperature)
Group 2	80% Soil + 20% shredded microplastics	14 days
Group 3	80% soil + 20% shredded microplastics	7 days

Sample Collection and Preparation

80 g of soil samples were collected using stainless steel hand trowel at a depth of 0−15 cm from Federal University Wukari farm, air-dried and sieved to obtain fine particles. The obtained soil samples were then mixed with microplastics (shredded nylon) ranging between 5mm and 1mm. They were arranged in three groups; one served as the control (Group 1), containing no shredded microplastics, whereas microplastics were shredded in Group 2 and Group 3 soil samples. They were all arranged in triplicates. The control group was kept at room temperature for 14 days whereas Group 2 was exposed to sunlight for 14 days. Group 3 was exposed to sunlight for 7 days. They were then poured into clean glass containers that were previously washed. The clean glass containers were labeled using a mask tape and a marker as Group 1, Group 2 and Group 3 respectively. The sample bottles were then transported to General Biochemistry Laboratory for further analysis.

Sample Extraction (Wet Peroxidation Method)

2.0g of samples each was weighed into a 250ml beaker and swirled properly then 40ml of aqueous 0.05M Fe (II) solution was added, followed by the addition of 40ml of 35% H_2O_2. All were mixed up properly for 5 minutes at room temperature. A stir bar was added to the beaker containing the samples and heated on a hot plate at 75^0C with watch glass cover on it, at the point where bubbles were observed, the beakers were removed from the hot plate and placed in the fume box until the boiling subsided. The mixtures were allowed to cool then they were filtered through a Whatman No4 filter paper into a 200ml volumetric flask each. The filtrate was subjected into centrifugation using a centrifuge machine at 5000 rpm i.e Revolution per a minute. The extracts of supernatant were transferred into a set of 50ml centrifuge tubes and stored in the fridge for the analysis of the detectable microplastics.

Conditioning of Waters 616/626 HPLC for Analysis of Microplastics

The name of the HPLC used for the analysis is waters incorporate, model of the HPLC is waters 616/626 HPLC. The wavelength range used is 415-425nm as imputed on the software, the detector is fluorescence detector. The sample parameters were separated isocratically on the reserved-phase L 18 column 5µm (25cm x 4.6mm)., produced by Supelco, Inc. USA. Also, the mobile phase consists of 40nm sodium phosphate dibasic heptahydrate and 20% acetonitrile (v/v), pH 6.5adjusted with 85% phosphoric acid. The column temperature was 25^0C. The flow rate was 0.85 ml per minute. The volume of suction or injection is 25 microliters. The column eluted were monitored by fluorescence

dictator manufactured by DULO-CHEM (Model 5020A). The dictation limit of the waters 616, 626 is 0.005 ppb (i.e part per billion). The working standard range of 0.0, 2.0, 4.0, 6.0, 8.0, ppm was used for the calibration of the instrument before running the samples of unknown concentration. The concentration of the various microplastic where calculated automatically using a digital software interfaced with the instrument. The final results were displayed on the computer read out in ug per kg for result reporting using the factors sample weight extraction volume, dilution factor. If any to calculate the ppm values of the various and total microplastics present in the samples of the unknown concentration.

Statistical Analysis

Special Package for Social Sciences (SPSS) version 23.0 was used to check for significant levels of all parameters measured. The level of significance for the ANOVA analysis and mean comparison was at $p<0.05$. The concentration of microplastics in all samples was expressed in μg\kg.

RESULTS

Microplastics Levels in Soil Samples Exposed to Room Temperature and Sunlight

The result presented in Table 2 and Figure 1 below revealed that a total of 8 microplastics (Polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol, terephthatic acid, acrylic acid and polyester) were found present in all the analysed soil samples. The result also revealed the concentration of each detected microplastic as well as the total concentration of microplastics present in each group of the analysed soil samples after exposure to room temperature and sunlight for a period of 7 days and 14 days.

The highest level of total detectable microplastics was associated with Group 3 soil samples (59314.95±808.35), followed by Group 2 soil samples (56022±1352.14) and lastly Group 1 (control) soil samples (32703.51±649.99) respectively (Table 2, Figure 1).

The result also revealed polyamide to be the most abundant microplastic present in all the analysed soil samples: Group 1 (28022.08±425.28), Group 2 (48977.99±1071.61), and Group 3 (52204.46±582.03) (Table 2, Figure 2), whereas the least level of microplastic present in all analysed soil samples was terephthatic acid shown as thus: Group 1 (211.32±14.77), Group 2 (369.36±28.11), and Group 3 (393.69±17.44) and respectively (Table 2, Figure 1).

The level of polystyrene was also revealed to be significantly high in Group 2 (1081.63±32.28\) and Group 3 (1152.88±40.48) soil samples, whereas in the control group, it was significantly low (618.84±27.51) (Figure 3). Polypropylene level was significantly high in Group 2 (1117.24±44.29) and Group 3 (1190.84±41.73) soil samples, where as in the control group, it was seen to be significantly low (639.21±28.65) (Figure 4).

The results revealed that polyethylene level was highest in Group 3 (2467.22±61.33[a]) soil samples compared to Group 2 (2314.73±67.43[a]) and Group 1 (1324.34±59.89[b]) soil samples (Figure 5). Ethylene glycol level was lowest in the control group (395.90±17.54[b]) compared to Group 2 (691.97±22.77 [a]) and Group 3 (737.56±25.49[a]) soil samples (Figure 6).

The result presented in Table 2 below revealed that terephthatic acid level was least present in the control group (211.32±14.77[b]), whereas it increased significantly in Group 2 (369.36±28.11[a]) and Group 3 (393.69±17.44[a]) soil samples (Figure 7). Acrylic acid level was highest in the control group (610.19±21.81[a]) and least in Group 3 (478.04±19.01[b]) soil samples (Figure 8). Polyester levels were observed to be highest in the control group compared to Group 2 (868.27±31.55[a]), whereas Group 3 (690.70±20.84[a]) soil samples (Figure 9).

Overall, the result revealed that soil samples exposed to sunlight for a period of 7 days (Group 3) had the highest level of detected microplastics followed by soil samples exposed to sunlight for 14 days (Group 2). The control group clearly showed the least levels of detected microplastics (Table 2, Figure 1).

Table 2. Levels of microplastics in soil samples exposed to room temperature and sunlight

Microplastics (µg/kg)	**Group 1**	**Group 2**	**Group 3**
Polyamide	28022.08±425.28[b]	48977.99±1071.61[a]	52204.46±582.03[a]
Polystyrene	618.84±27.51[b]	1081.63±32.28\[a]	1152.88±40.48[a]
Polypropylene	639.21±28.65[b]	1117.24±44.29[a]	1190.84±41.73[a]
Polyethylene	1324.34±59.89[b]	2314.73±67.43[a]	2467.22±61.33[a]
Ethylene glycol	395.90±17.54[b]	691.97±22.77 [a]	737.56±25.49[a]
Terephthatic acid	211.32±14.77[b]	369.36±28.11[a]	393.69±17.44[a]
Acrylic acid	610.19±21.81[a]	600.94±27.90[a]	478.04±19.01[b]
Polyester	881.63±36.55[b]	868.27±31.55[a]	690.70±20.84[a]
Total detectable MPs	32703.51±649.99[b]	56022±1352.14[a]	59314.95±808.35[a]

*Results are expressed in mean ± standard deviation of triplicate determination

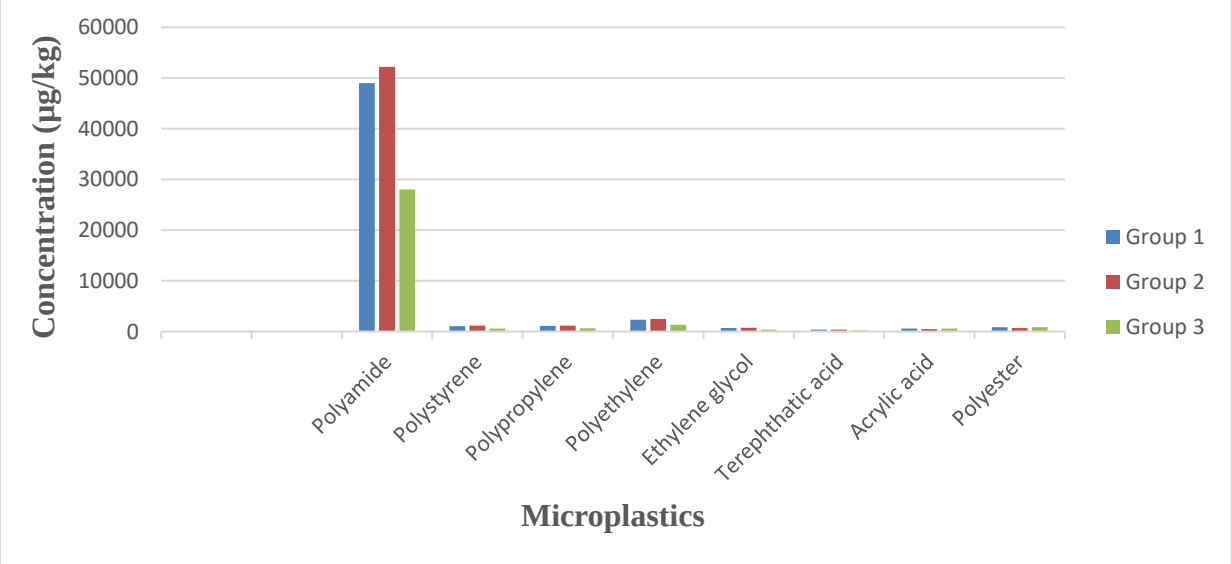

Figure 1. Levels of microplastics in soil samples exposed to room temperature and sunlight

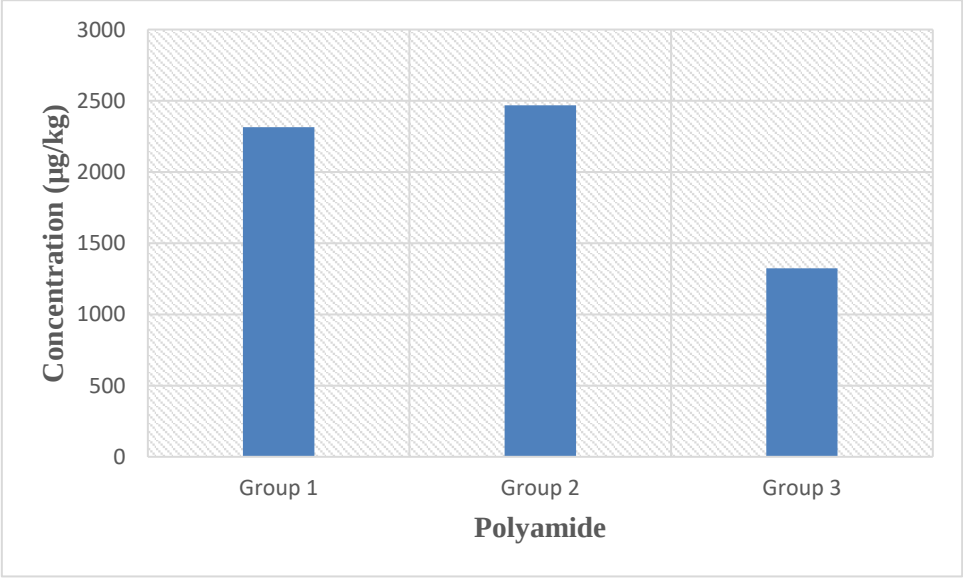

Figure 2. Polyamide levels present in soil samples exposed to room tempearture and sunlight

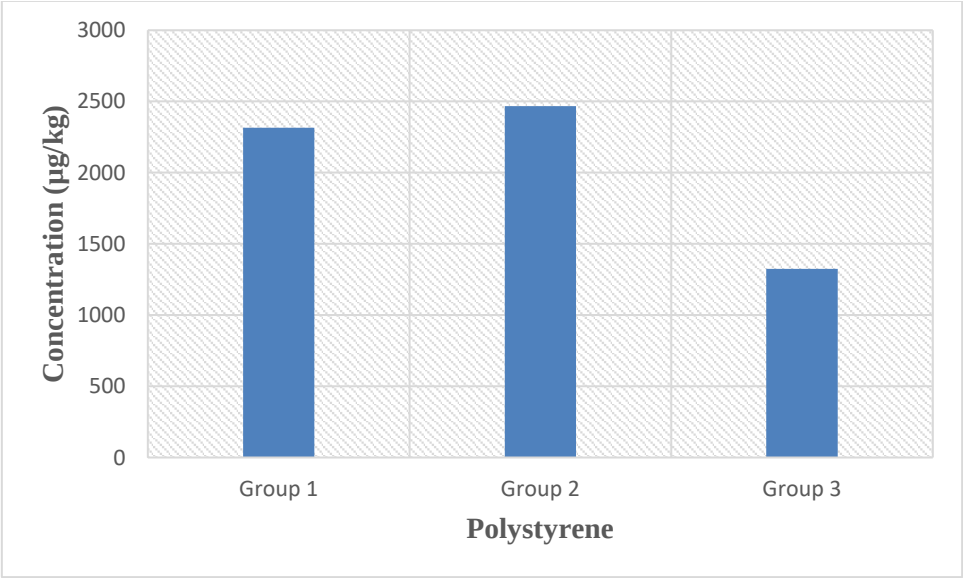

Figure 3. Polystyrene levels present in soil samples exposed to room tempearture and sunlight

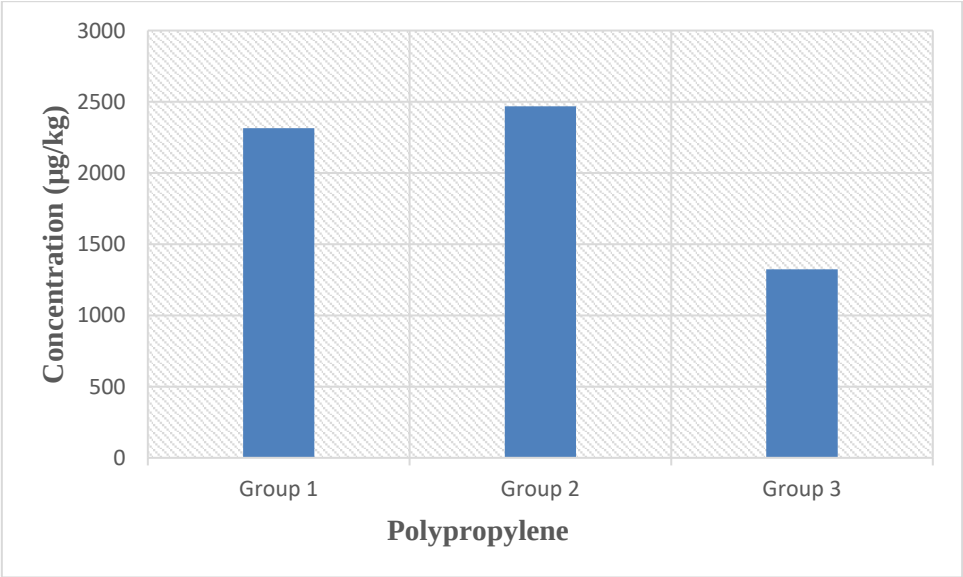

Figure 4. Polypropylene levels present in soil samples exposed to room tempearture and sunlight

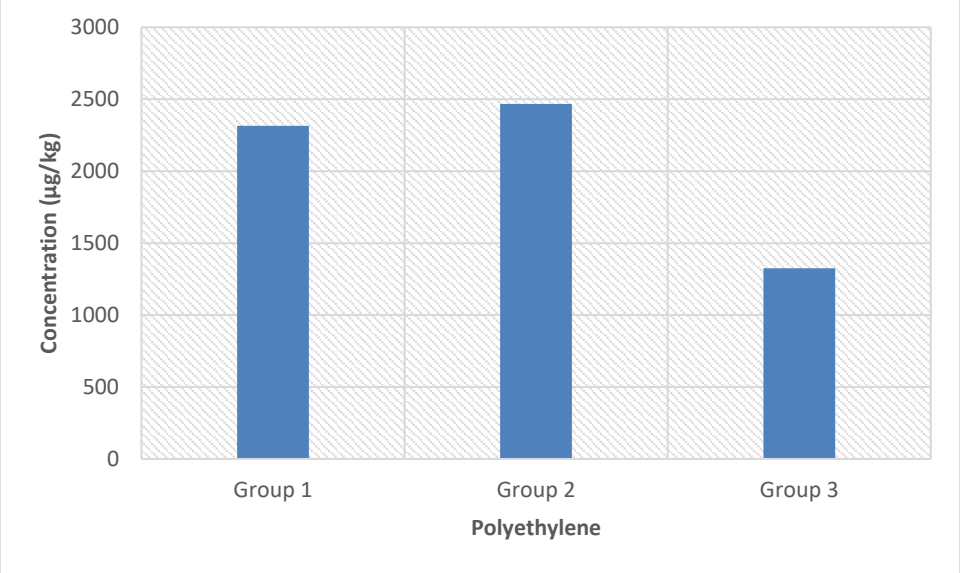

Figure 5. Polyethylene levels present in soil samples exposed to room tempearture and sunlight

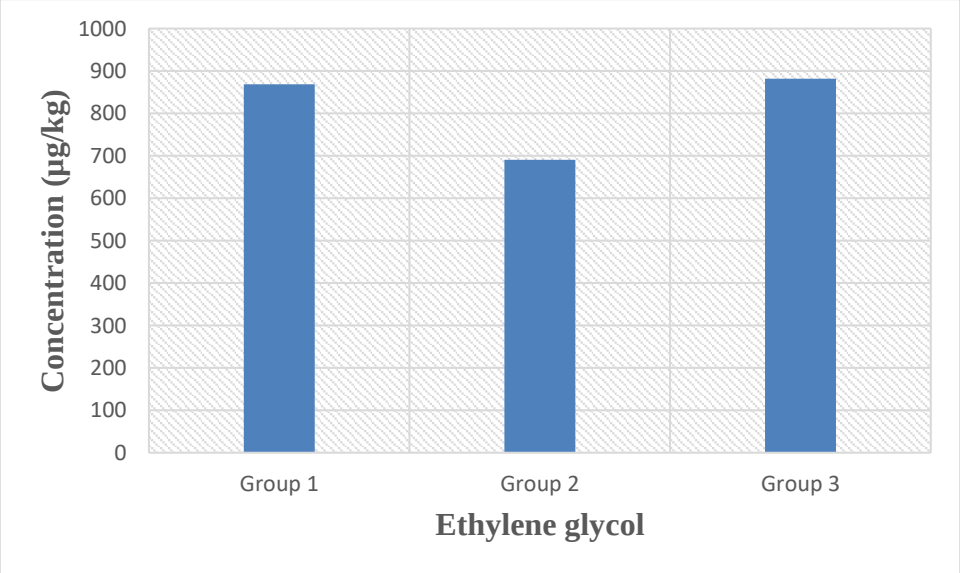

Figure 6. Ethylene glycol levels present in soil samples exposed to room tempearture and sunlight

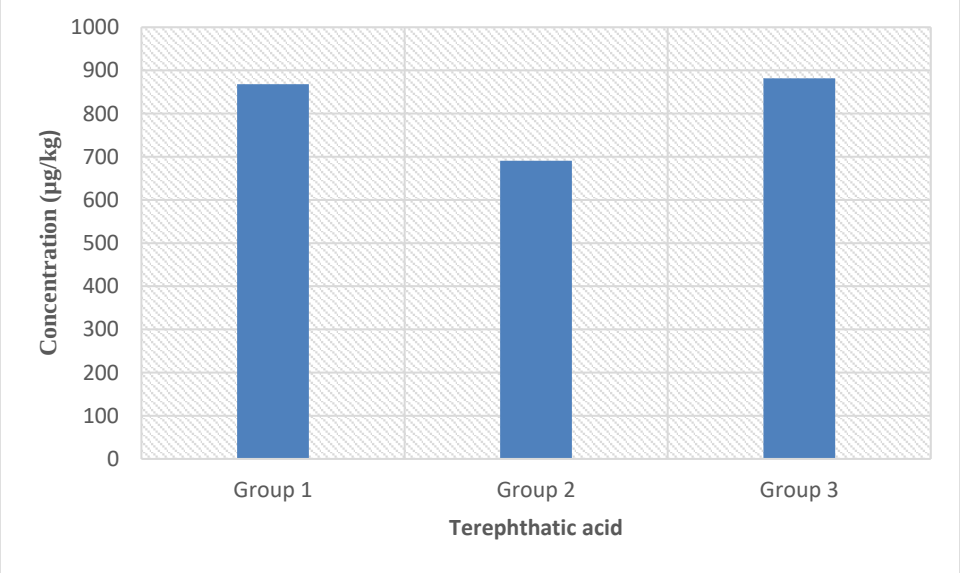

Figure 7. Terephthatic acid levels present in soil samples exposed to room tempearture and sunlight

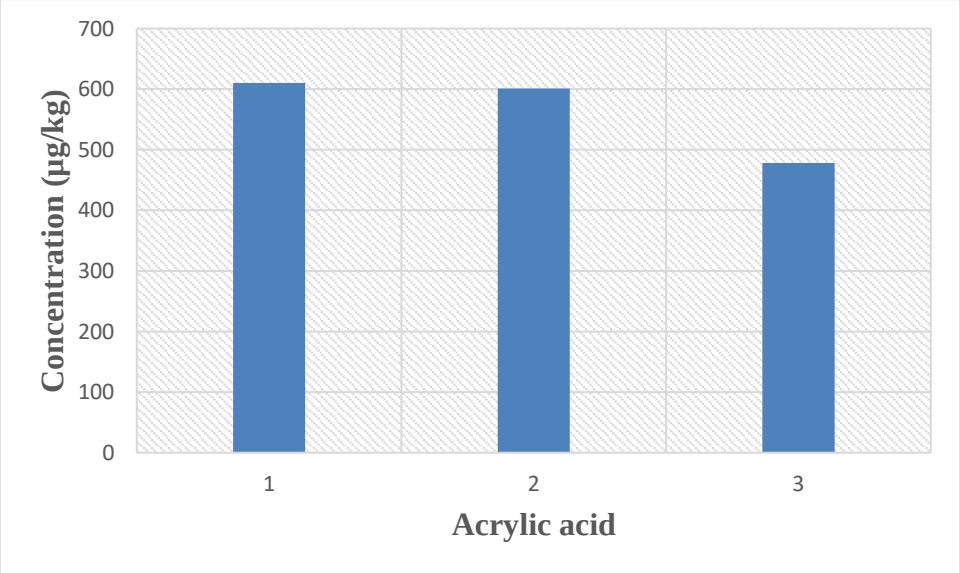

Figure 8 Acrylic acid levels present in soil samples exposed to room tempearture and sunlight

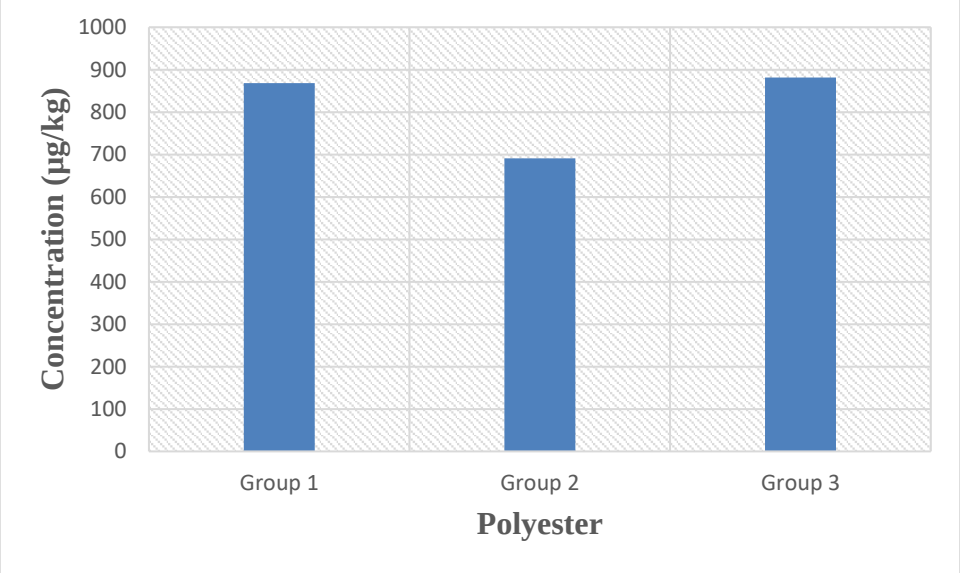

Figure 9. Polyester levels present in soil samples exposed to room tempearture and sunlight

DISCUSSION

The contamination of soil caused by the degradation of plastics introduced through indiscriminate disposal has been increasing globally (Ali *et al.*, 2021, Otitoju et al., 2022). Researchers have reported that exposure to microplastics, the degradative product of plastic materials triggers a "wide variety of toxic insults". Swimming in, eating, ingesting microplastics disrupts reproductive performance, eating habits, metabolism, and changes liver physiology, to name just a few major concerns (Ya *et al.*, 2021; Zhou *et al.*, 2021).

The present study investigated the effect of temperature on microplastic degradation in soil environment. Eight microplastics were found present in all the soil samples that were analysed. Out of the eight microplastics present, polyamide was found to be the most abundant microplastic present in all the assayed soil samples: whereas the least microplastic present in all assayed soil samples was terephthatic acid. This is an indicative of the fact that there is high use of polyamide associated polymer which upon indiscriminate disposal could result to its breakdown yielding polyamide as a degradative product. However, certain plastic polymers may be made up of other chemicals which upon degradation can yield less amounts of their associated products (Rilling *et al.,* 2021).

The level of polystyrene was revealed to be significantly high in Group 2 (1081.63±32.28\) and Group 3 (1152.88±40.48) soil samples, whereas in the control group, it was significantly low (618.84±27.51) (Figure 3). Polypropylene level was significantly high in

Group 2 (1117.24±44.29) and Group 3 (1190.84±41.73) soil samples, where as in the control group, it was seen to be significantly low (639.21±28.65) (Figure 4). Temperature has been reported by many researchers to be one of the key factors that facilitates the breakdown of microplastics (Saikrasun and Saengsuwan, 2009). This is affirmed by the findings of this study. It could be observed that soil samples that were exposed to sunlight for 14 days showed lower amount of polystyrene and polypropylene compared soil samples exposed to sunlight for 7 days. The findings of Laura et al. (2023) also agrees with this assertation.

Overall, the result revealed that soil samples exposed to sunlight for a period of 7 days (Group 2) had the highest level of individually detected microplastics followed by soil samples exposed to sunlight for 14 days (Group 1). The control group clearly showed the least levels of individually detected microplastics. When microplastics get exposed to sunlight, the UV ray that hits on the microplastics have the propensity to fragment them. This implies that the longer the exposure of a microplastic material to UV rays, the higher the degradation rate. The higher the degradation rate, the more microplastic intermediates that will be yielded thus, is decreasing the initial fraction of microplastics before the onset of degradation. On the other hand, the shorter the period of exposure of a microplastic material to UV rays, the lower the degradation rate, and the lesser the presence of microplastic intermediates that would be yielded. This accounts for why Group soil samples which were exposed UV rays for 7 days showed higher levels of microplastics connoting lower degradation rate compared to soil samples that were exposed for 14 days to UV rays (Ranjan *et al.,* 2021).

On the basis of microplastic toxicity, certain microplastics have been reported by many researchers to undergo degradation yielding less harmful intermediates. Others can be degraded to intermediates that could be used up by microbes as carbon source. However, other microplastics undergo degradation to form more toxic intermediates which could pose threat to soil organisms and even terrestrial and aquatic organisms at large (Otitoju and Moses, 2022).

CONCLUSION

The study revealed that microplastics upon exposure to UV rays from sun light could undergo degradation yielding several intermediates which may be either more or less harmful. The study also revealed that the longer the exposure of a microplastic material to UV rays, the higher the degradation rate and the more intermediates associated with the microplastic material will be yielded. Contrarily, the shorter the exposure time of a microplastic material to UV rays, the lesser the degradation rate and less intermediates associated with the microplastic material will be yielded.

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REFERENCES

Bläsing, M., and Amelung, W. (2018). Plastics in Soil: Analytical Methods and Possible Sources. Sci. Total Environ. 612, 422–435. doi: 10.1016/ j.scitotenv.2017.08.086.

Boots, B., Russell, C. W., and Green, D. S. (2019). Effects of Microplastics in Soil Ecosystems: Above and below Ground. Environ. Sci. Technol. 53 (19), 11496–11506. doi:10.1021/acs.est.9b03304.

de Souza Machado, A. A., Lau, C. W., Till, J., Kloas, W., Lehmann, A., Becker, R., et al. (2018). Impacts of Microplastics on the Soil Biophysical Environment. Environ. Sci. Technol. 52 (17), 9656–9665. doi:10.1021/acs.est.8b02212.

Fei, Y., Huang, S., Zhang, H., Tong, Y., Wen, D., Xia, X., et al. (2020). Response of Soil Enzyme Activities and Bacterial Communities to the Accumulation of Microplastics in an Acid Cropped Soil. Sci. Total Environ. 707, 135634. doi:10.1016/j.scitotenv.2019.135634.

Geyer, R., Jambeck, J. R., and Law, K. L. (2017). Production, Use, and Fate of All Plastics Ever Made. Sci. Adv. 3 (7), e1700782.

Hargreaves, S. K., and Hofmockel, K. S. (2014). Physiological Shifts in the Microbial Community Drive Changes in Enzyme Activity in a Perennial Agroecosystem. Biogeochemistry 117, 67–79. doi:10.1007/s10533-013-9893-6

Laura M. Hernandez, Joel Grant, Parvin Shakeri Fard, Jeffrey M. Farner, Nathalie Tufenkji, (2023). Analysis of ultraviolet and thermal degradations of four common microplastics and evidence of nanoparticle release. *Journal of Hazardous Materials Letters*,Volume 4, 100078.

Lehmann, A., Leifheit, E. F., Gerdawischke, M., and Rillig, M. C. (2020). Microplastics Have Shape- and Polymer-dependent Effects on Soil Processes. BioRxiv 12, 339–344. doi:10.1101/2020.06.02.130054

Liang, Y., Lehmann, A., Yang, G., Leifheit, E. F., and Rillig, M. C. (2021). Effects of Microplastic Fibers on Soil Aggregation and Enzyme Activities Are Organic Matter Dependent. Front. Environ. Sci. 9, 650155. doi:10.3389/ fenvs.2021.650155

Lozano, Y. M., Lehnert, T., Linck, L. T., Lehmann, A., and Rillig, M. C. (2021a). Microplastic Shape, Polymer Type, and Concentration Affect Soil Properties and Plant Biomass. Front. Plant Sci. 12. 616645 doi:10.3389/ fpls.2021.616645

Mai, L., Bao, L.-J., Wong, C. S., and Zeng, E. Y. (2018). "Microplastics in the Terrestrial Environment," in Microplastics in the Terrestrial Environment. Microplastic Contamination in Aquatic EnvironmentsEddy Zeng. 1st edition (Elsevier), 365–378. doi:10.1016/B978-0-12-813747-5.00012-6

Otitoju O, Moses A.A, Otitoju T.G, Bilyaminu H, Emmanuel C.O, Patience U.O. (2022). Risk assessment of pesticide residues in water samples from river Gongola, Adamawa state, *Nigeria World Journal of Advanced Research and Reviews*, 13(01), 424–432

Otitoju Olawale and Moses A. Abah (2022). Determination of Particulate Matter In Residential Buildings in Wukari, Taraba state, Nigeria. *Journal of Research in Environmental and Earth sciences.* 8(2)30-34.

Otitoju, O., Abah A.M., Okonkwo F.O. (2021). Determination of indoor volatile organic compound levels in some residential areas in Wukari, Taraba State, Nigeria. *Global Scientific Journals*, 9(12): 1050-1057.

Ranjan, V.P., Joseph, A. and Goel, S. (2021). Microplastics and other harmful substances released from disposable paper cups into hot water. *Journal of Hazardous Materials*, *404*, p.124118.

Rillig, M.C., Lehmann, A., 2020. Microplastic in terrestrial ecosystems. Science. 368, 1430–1431.

Saikrasun, S. and Saengsuwan, S. (2009). Thermal decomposition kinetics of in situ reinforcing composite based on polypropylene and liquid crystalline polymer. *journal of materials processing technology*, *209*(7), pp.3490-3500.

Wiedner, K., and Polifka, S. (2020). Effects of Microplastic and Microglass Particles on Soil Microbial Community Structure in an Arable Soil (Chernozem). Soil 6, 315–324. doi:10.5194/soil-6-315-2020

Yi, M., Zhou, S., Zhang, L., and Ding, S. (2020). The Effects of Three Different Microplastics on Enzyme Activities and Microbial Communities in Soil. Water Environ. Res. 93 (1), 24–32. doi:10.1002/wer.1327

Yu, H., Fan, P., Hou, J., Dang, Q., Cui, D., Xi, B., et al. (2020). Inhibitory Effect of Microplastics on Soil Extracellular Enzymatic Activities by Changing Soil Properties and Direct Adsorption: an Inverstigation at the Agregate-Fraction Level. Environ. Pollut. 267, 11554. doi:10.1016/j.envpol.2020.115544

Zhou, J., Gui, H., Banfield, C.C., Wen, Y., Zang, H.D., Dippold, M.A., Charlton, A., Jones, D.L. (2021). The microplastisphere: Biodegradable microplastic addition alters soil microbial community and function. Soil Biol. Biochem. 156, 108211.