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Biowaste compost amendment is a source of microplastic pollution in agricultural soils

Sindujaa A.M., Dhinagaran G.* and Merline Sheela A.
Centre for Environmental Studies, Department of Civil Engineering, Anna University, Chennai – 600 025, Tamil Nadu, India
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*to whom all correspondence should be addressed: e-mail: twinsdina@gmail.com
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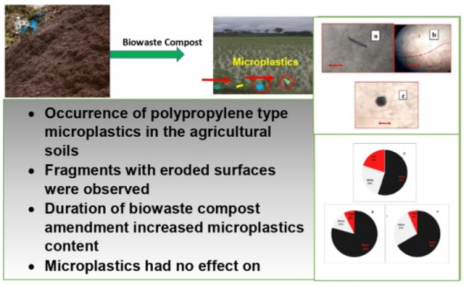
Graphical abstract



Abstract

Microplastics were discovered in soil samples taken from fields in Tamil Nadu, India's Ponneri, Redhills, and Thirumazhisai where the fields had been amended with compost made from biowaste. The soil sample taken from agricultural field in Ponneri had the highest microplastic level, which was determined to be 3.28±0.8 g/kg. The duration of compost addition has a big impact on how microplastics are distributed. When compared to Redhills (5 years' compost amendment) and Thirumazhisai (3 years' compost amendment), the agricultural fields of Ponneri had greater microplastic concentration after 8 years of biowaste compost amendment. The Scanning Electron Microscope (SEM) analysis revealed the presence of multiple forms of microplastics in the study area, including fragments, fibres, and pellets. SEM research confirmed that the surface topography of microplastics exhibited cavities and cracks as a result of weathering activity. Fourier transform infrared (FTIR) spectroscopy analysis confirmed that polypropylene type microplastic was present in the study area. Additionally, the presence of microplastics in the biowaste compost had no impact on the bacterial population or microbial activity in the soil.

Keywords: Agricultural soils, biowaste compost, microplastics distribution, soil microbial activity

1. Introduction

Our daily lives are becoming more and more reliant on plastic. The annual global production of plastic is about 322 million tonnes (Zhang *et al.,* 2020). A whopping 85% of used plastics are not recycled and end up in the environment (Alabi *et al.*, 2019), where solar radiation and weathering cause them to disintegrate into small bits known as microplastics (Andrady 2022; Zhang *et al.*, 2020). The particle size of the microplastics is 1– 5000 µm (Frias *et al.*, 2019) and are considered as emerging pollutants that have a severe impact on the ecosystem (Sharma *et al*., 2017; Townsend *et al.*, 2019; Prata *et al.*, 2020). Plastics are introduced into soils through sewage sludge (Corradini *et al.,* 2019; Schell *et al.*, 2022), irrigation, soil runoff (Pérez-Reverón *et al.*, 2022; Henry *et al.*, 2019), and plastic film mulching (Kumar and Sheela, 2022; Khalid *et al.*, 2023). Another source of soil microplastics (Blasing and Amelung 2018; Scopetani *et al.*, 2022; Zhang *et al.*, 2022) is the addition of compost to fields. Compost made from various raw materials, including kitchen waste (Yang *et al.*, 2019), poultry litter (Cao *et al.*, 2022; Sinduja *et al.*, 2021), cow manure (Haroon *et al.*, 2022), garden waste (Langsdorf *et al.*, 2021), and vegetable waste (Ghinea and Leahu 2020), is frequently used in agricultural fields to boost the growth of crops. Municipal solid waste (MSW) compost is currently used to enhance the physicochemical characteristics of soil, including soil structure, water holding capacity, buffering capacity, nutritional status (Kranz *et al.*, 2020), and microbial biomass and activity (Azeem *et al.*, 2022; Mandal et al., 2020). India's per capita generation of solid waste is rising as a result of urbanisation, industrialization, and economic expansion (Kumar *et al.*, 2017).

In India, there are over 133760 tonnes of Municipal Solid Waste (MSW) produced per day (CPCB India 2018). It comprises of home garbage, non-hazardous solid waste thrown by industrial, commercial and institutional institutions, market waste, yard waste and street sweepings (Sharma and Jain 2019; Kranz *et al.*, 2020). MSW is processed to provide energy and compost since it has a high organic matter content (Joseph *et al.*, 2012). The MSW's separated organic part can be composted right away (Kumar and Agarwal 2022). The compost generated from MSW is the source of undesirable inert materials like plastic, glass, and metals that could vause harmful effects to the plants (Balasubramanian 2018). Microplastics are mainly found in the MSW compost due to food waste and sludge/biosolids (Golwala *et al.*, 2021). Moreover, the compost of household waste has microplastics derived from synthetic fibers from clothing and personal care products (Hernandez *et al.*, 2021). Microplastics of various forms and types can also be found in compost made from rural domestic waste (Gui *et al.*, 2021). Plastic particles were abundant (12±8–46±8 particles/kg) in various types of compost tested (Braun *et al.*, 2021). The primary source of plastic particles in the compost may also be the disposal of packaged food waste in the organic waste bin (Katharina *et al.*, 2020). A potential cause of microplastic pollution is the amendment of biowaste compost for agricultural and horticultural crops (Porterfield *et al.*, 2023). Plastics were introduced into arable soils as a result of MSW compost amendment (Blasing and Amelung 2018). Microplastics have been studied in soil amended with MSW compost for ten years (Watteau *et al.*, 2018). However, the vast majority of studies are concentrated on aquatic ecosystems, and there is very little information on microplastic pollution in terrestrial environments. Furthermore, no research has yet been done in India to look into the presence of microplastics in agricultural soil that has been modified using compost made from biowaste. Therefore, the current study was carried out to (1) examine the microplastics in agricultural soils and horticultural soils amended with biowaste compost, (2) investigate the effect of microplastic distribution on soil bacterial population, (3) study the correlation between microplastic content and soil microbial activity.

2. Materials and methods

2.1. Sampling site

The samples were obtained from three different agricultural soils in the Thiruvallur District of Tamil Nadu, where the soils were amended with biowaste compost: Ponneri (13°20'31.6"N 80°11'54.9"E), Redhills (13°11'47.0"N 80°11'11.0"E) and Tirumazhisai (13°03'17"N 80°03'12"E). According to Periyasamy *et al*. (2018), the district receives an average range of 970 to 1100 mm of precipitation each year. Tube wells are the source of irrigation for the chosen study locations. The details of the crop grown in the study area and the duration of biowaste compost amendment are shown in Table 1.

The paddy crop was rotated with groundnut or pulse crops in the Ponneri and Thirumazhisai regions. In Redhills, vegetable crops including brinjal were sown in the field. Biowaste compost was used to amend fields in Ponneri, Redhills, and Thirumazhisai for 8, 5, and 3 years, respectively. The compost was amended @ 20 t/ha obtained from same source. Figure 1 depicts where the sampling fields are located.

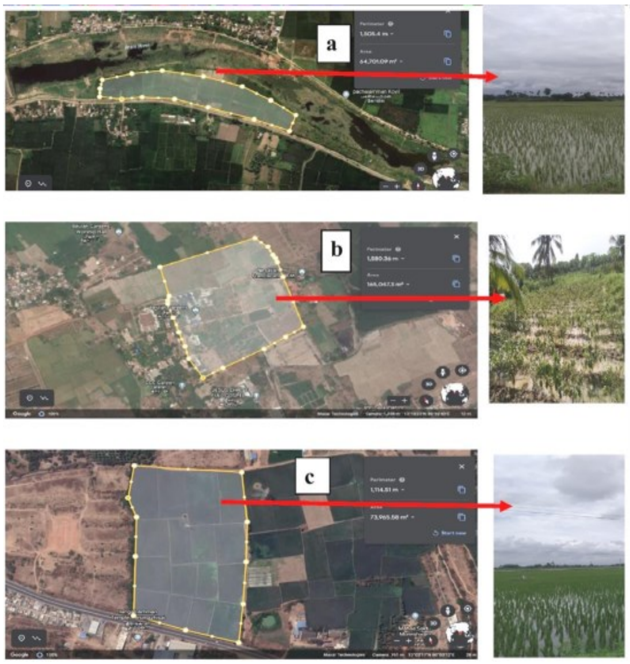


Figure 1. Locations of sample collection (a) Ponneri (b) Redhills (c) Thirumazhisai

Table 1. Particulars about the agricultural field where the study was conducted

Location	Crop grown during sampling	Area of land (ha)	Crop rotation followed with	Duration of compost amendment (years)
Ponneri	Paddy (*Oryza sativa*)	6.47	Groundnut(*Arachis hypogaea*), Greengram (*Vigna radiata*), Blackgram (V. mungo)	8
Redhills	Brinjal (*Solanum melongena*)	16.18	Greengram (*V. radiata*), Sesame (*Sesamum indicum*)	5
Thirumazhisai	Paddy (*Oryza sativa*)	6.07	Blackgram (*V. mungo*), Greengram (*V. radiata*)	3

2.2. Sample collection

The soil samples were obtained from the agricultural fields of Ponneri, Redhills and Thirumazhisai and amended with biowaste compost. Each field was divided into four segments. In each segment, 5 m from the edge a 3 × 3 m^2 size square plot was marked, and from within the plot, five samples (each 1 kg) were obtained at a depth of 10–30 cm randomly using a spade (Schell *et al*., 2022) A composite sample was created by combining the collected samples. Similar to the fourth sample, the fifth was also taken from the middle of the field. From each location, a control soil (virgin) sample was collected from 500 m distal to the biowaste compost amended field as a reference. The samples were then packed in squeaky-clean glass bottles and transported to the laboratory in an ice box. Subsequently, the clumps of samples were broken to obtain a homogeneous sample. The samples were dried in the air before stones and plant debris were manually removed. The powdered air-dried soil was put in glass containers and stored at 4^{o}C for further study.

2.3. Characterization of soil samples

The parameters, such as pH (1:2.5 (soil:water)) using pH metre (Elico L1120), electrical conductivity (EC) using a digital conductivity metre (Labline) (Jackson 1973) and total organic carbon (TOC) (Walkley and Black 1934), were determined.

2.4. Extraction and identification of microplastics

The soil samples were first dried at 70 °C in an oven before being sieved with a mesh size of 20. Then, 100 mL of saturated NaCl (AR, 99.5%, 8.0% w/v; ρ=1.2 g/cm^3) was added to the 250-mL conical flasks with the sieved material, and the combination was incubated for 24 hours. The mixture was then treated with hydrogen peroxide (H_2O_2 35%) (Dubaish and Liebezeit 2013) to eliminate the organic material before being filtered through a filter assembly (pore size 1–6 μm). Subsequently, the filtrates were dried at 60 °C in a hot air oven (Model BST/HAO-1122; Bionics Scientific Technologies (P) Ltd, India) for 24h. The amount of microplastic in the samples was measured using the initial and final weights of the filter paper.

Microplastics were classified into three categories based on the findings of the visual analysis performed using a stereomicroscope (Accu-Scope; Thermo Scientific Inc.): absence of visible cellular or organic structures in the microplastics, uniformity along the entire length of the fibres, and clear and homogeneous colours (Qiu *et al.*, 2016). Microplastics were divided as fragments, films (thin, soft, and filmy), fibres (elongated), and pellets based on the observations (Jabeen *et al.*, 2017). Furthermore, using SEM-Edx (Carl Zeiss MA15/EVO 18, resolution of 3.0 nm with a 30-kV SE detector), the surface morphology and elemental concentration of the selected microplastics were evaluated. Using double-sided adhesive carbon tabs, the microplastic samples were fixed to the aluminium SEM stubs (Wang*et al.*, 2017). Using an EmCrafts Virtuoso 1.1 operating at 20 kV at a working distance of 15 nm, the samples were photographed (Tiwari *et al.*, 2017). The polymer type of the microplastics was determined using an IR Affinity-1S FTIR spectrophotometer (Shimadzu, Japan). The FTIR spectra were averaged over 500 scans and measured in the wavelength range of 500-4000 cm^{-1} at a resolution of 4 cm^{-1} (Tiwari *et al.*, 2017). The FTIR absorbance spectra of the microplastics were compared to those in the OMNIC polymer reference library to identify the particles.

2.5. Biological characteristics

The soil microbial population of bacteria was enumerated using soil extract agar medium (Allen 1957). The data are represented as colony forming units (CFU)/g soil (dry weight basis). The biological reduction of triphenyl tetrazolium chloride (TTC) by microorganisms was used to estimate the dehydrogenase enzyme activity, which is a measure of microbial activity (Casida 1964).

2.6. Quality control/quality assurance

Deionized water was used to thoroughly clean all equipment and containers prior to use. In order to get a composite sample, five samples were taken from each sampling point. The samples were promptly moved to glass vials and closed to avoid on site contamination. The samples were transported in an ice box to preserve the viability of the bacterial species. Analytical-grade chemicals were used for all of the analyses. Deionized water was used to create each and every reagent used in this study. Plastic materials were not used in the analysis of microplastics. The sieve, mesh and mortar and pestle used were made of stainless steel. Also, in the working space, the furnishing and carpeting materials comprised of synthetic fibers were avoided. The work table was cleaned with alcohol prior to the analysis beginning. In order to prevent contamination from synthetic fibres and hairs during conducting the experiments, a white cotton coat, cap, and gloves were worn throughout the extraction of microplastics. The samples were always kept in a closed condition. The spectrophotometer was calibrated using the blank solution (10mL of 0.2 M $Fe(NO_3)_3$ diluted to 25 mL with 0.1 M HNO_3) prior to taking readings to determine the dehydrogenase enzyme activity. Furthermore, each analysis was carried out in five replicates to obtain an accurate result.

2.7. Data analysis

The data were statistically analyzed using SPSS 19.0 and the results were presented as mean±standard error of the mean.

3. Results and discussion

3.1. Physicochemical characteristics

The data are shown in Table 2 for the parameters such as pH, EC, and TOC that were examined for the soil samples taken from Ponneri, Redhills, and Thirumazhisai. The parameters were pH 7.1–7.6, EC 72.3–81.2 μS/cm, and TOC 19.12±1.2–23.5±1.4%. As a result, it was found that the characteristics of the samples taken from various study areas varied only little from one another. The outcomes matched those of previous studies (Chandrasekaran and Ravisankar 2015; Kumar and Sheela 2021). The characteristics of the soil are determined by the type of soil and the amount of organic matter in surface soils (Schilatter *et al.*, 2017).

Table 2. Physicochemical characteristics of soil samples

Parameter	Sampling locations					
	Ponneri		Redhills		Thirumazhisai	
	Control	Sample	Control	Sample	Control	Sample
pH	7.3	7.2	7.1	7.0	7.2	7.6
EC (μS/cm)	74.1	72.6	75.9	79.8	81.2	72.3
TOC (%)	20.5±(1.6)	20.13±(1.5)	19.2±(1.2)	22.3±(1.8)	23.5±1.4	22.5±(1.2)

TOC – Total Organic Carbon, Values in parenthesis represent ± Standard Error (n= 5)

3.2. Microplastic content in the study area

The microplastic content in the sampling locations, Ponneri, Redhills and Thirumazhisai, was determined and shown in Figure 2(a).

The microplastic content in samples taken from Ponneri, Redhills, and Thirumazhisai ranged from 0.29±0.1–3.28±0.8, 0.42±0.1–1.83±0.2 and 0.36±0.2–1.82±0.2 g/kg soil, respectively. According to the results, soil samples taken from Ponneri's agricultural areas contain more microplastic than those taken from Redhills and Thirumazhisai. Figure S1 (b) shows the impact of the duration of biowaste compost addition on the presence of microplastic in agricultural soils. We found that the micriplastic content increased with the duration of compost amendment. The soils collected from Ponneri, where compost addition was carried out for 8 years, reported the highest microplastic content compared to Redhills and Thirumazhisai.

Microplastics were discovered in soil samples collected from three different locations in the Thiruvallur District of Tamil Nadu, India, for the current study. However, understanding of the presence of microplastics in the terrestrial environment, particularly in agricultural soils, is still inadequate. Only a small number of recent studies have shown the accumulation of plastic debris in agricultural soils (da Costa 2018). The Chen *et al*. study (Chen *et al.*, 2020) confirmed the existence of microplastics in the Chinese agricultural soils. Previous studies confirmed the existence of microplastics in agricultural soils as the outcome of sewage sludge discharge (Corradini 2021), treating effluents for irrigation of crops (Li *et al*., 2022; Kumar et al., 2020), mulching with plastic film (Huang *et al*., 2020; Kumar and Sheela 2021), and compost (Watteau *et al*., 2018).

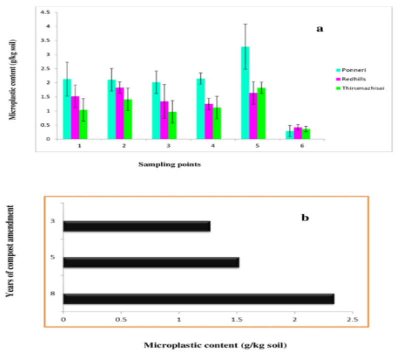


Figure 2(a) Microplastic content in different locations of the study area (Error bars represent ± S. E (n = 5)) & 2(b)Effect of duration of biowaste compost amendment on the occurrence of microplastics in agricultural soils

In the present study, neither treated effluent nor sewage sludge were used to modify the soils. Additionally, there was no plastic film mulching in this study area. In addition to sewage sludge and plastic mulches, the study by Huang 2020 *et al*, found that compost amendment was another source of microplastic pollution in agroecosystems. Composting is applied to agroecosystems all over the world to increase crop growth and yield (Wei *et al.*, 2000). When farmers fertilise their cultivable land with sewage sludge and compost made from biosolids, they unintentionally add microplastics to the soil (Henseler *et al.*, 2020). As an outcome, the presence of microplastics in the study area is attributable to the biowaste compost's amendment. Solid waste is a substantial source of microplastics in a range of sizes and shapes (Golwala *et al.*, 2021). Biowaste from MSW is often segregated and composted. However, household biowaste is sometimes not properly separated or disposed of in high-density plastic bags (Zumstein *et al*., 2018; Melgarejo *et al.* 2000). Furthermore, plastic containers used for packaging food are disposed of with spoiled food or leftovers to the biowaste collection bins. It is difficult to separate or remove the plastic particles once they have mixed with the biowaste (Weithmann *et al.*, 2018). In addition, the biodegradable plastic materials are not fully biodegraded in the composting plants because of less process period (Mallikarjuna and Bindu 2016; Pathan *et al.*, 2020). Possible pathways for plastics to enter agricultural soils include compost that has been modified with plastic particles. These particles are further broken down into smaller particles, called microplastics, when exposed to sunshine and UV rays (Shimizu *et al.*, 2017). These then form aggregates with the soil's organic matter particles and stay in the ground for a long time (Peng *et al.*, 2017). In the current study, microplastics have been identified up to a depth of 30 cm. The movement of microplastics into deeper layers is achieved by the colonization of micro arthropods (Maaß *et al.*, 2017), which is a conventional tillage practice (Paustian *et al.*, 2000).

3.3. Type and forms of microplastics

Figure 3 displays the many kinds of microplastics that were investigated in the study. In Ponneri samples, there were 450 ± 25, 300± 25 and 250±10 pellets, pieces, and fibres that were evaluated. The Redhills samples had 320±20, 200±20, and 100±12 fragments, pellets, and fibres, respectively. The samples from Thirumazhisai also contained 50, 18, 60, and 38 fragments, pellets, and fibres, respectively. According to the findings, fragments of microplastics were found most frequently in each of the three locations.

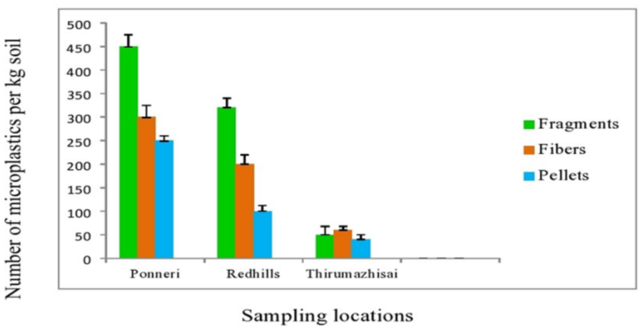


Figure 3. Different types of microplastics observed in the study area (Error bars represent ±Standard Error, n = 5)

In all the locations microplastics in black color was predominant. The other colors examined were white and red. The percent distribution of black, white and red color microplastics in samples of Ponneri was 55%, 25% and

20% respectively. The samples of Redhills harbored 79% (black), 18% (white) and 8% (red) microplastics. The samples collected from Thirumazhisai contained 67% (black), 27% (white) and 6% (red) microplastics (Figure 4).

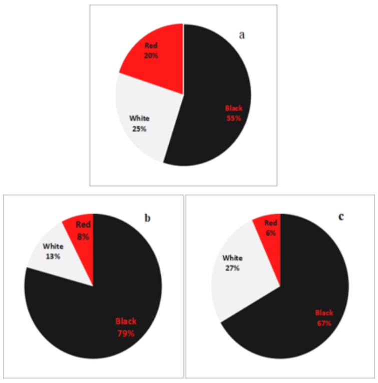


Figure 4. Percent distribution of different colours of microplastics in the study area (a) Ponneri (b) Redhills (c) Thirumazhisai

The microplastics found in the research area were identified as fibres, pellets, and pieces (Figure 5). A rough surface with eroded cavities was visible in the morphology under SEM (Figure 6). According to the peaks and heights of the peaks, the SEM- Energy Dispersive X-Ray analysis indicated the existence of various secondary elements at various concentrations (Figure 6(a)). Carbon (C), oxygen (O), iron (Fe), aluminium (Al), silicon (Si), and chlorine (Cl) were the elements that were found.

The presence of microplastics of the polypropylene type has been confirmed by the FTIR polymer type analysis of the fragments collected from the study area (Figure 6(b)). The presence of microplastics of the polypropylene type in the studied areas was established by the mapping of the intensity of bands (2905-C-H stretching; 1415-C=O stretching).

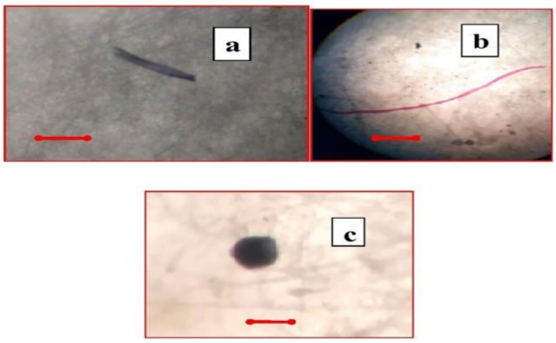


Figure 5. Photomicrograph of different forms of microplastics examined in the study area (a) Fragment (b) Fiber (c) Pellet (Examined at 45x magnification. Scale bars represent 200µm)

3.4. Effect of microplastics on biological characteristics

In soil samples taken from Ponneri, the bacterial population was 2x10^5 cfu/g (control), 8x10^5 cfu (field), 6x10^5 cfu/g (control), 9x10^5 cfu/g (field samples), 4x10^6 cfu/g (control), and 12x10^6 cfu/g (field sample) (Figure 7(a)). The dehydrogenase enzyme activity of the soil samples taken from the study area has been determined and the data is displayed in Figure 7b. The soil samples taken from Ponneri had the highest dehydrogenase enzyme activity, 0.94 µg Triphenyl Formazon (TPF) formed/h/g, while the soil samples taken from Thirumazhisai had the lowest dehydrogenase enzyme activity, 0.81 µg TPF formed/h/g. Furthermore, for the soils in Ponneri, Redhills, and Thirumazhisai, the dehydrogenase activity was 0.89, 0.74, and 0.79µg TPF formed/h/g, respectively.

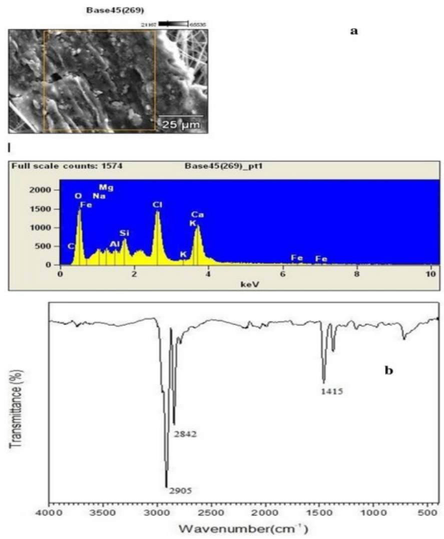


Figure 6. (a) SEM–EDX spectra to confirm the presence of individual elements in the plastic particle (b) FTIR spectrum of Polypropylene type microplastic in the study area (Horizontal axis represents the spectral range and vertical axis represents the transmittance %.)

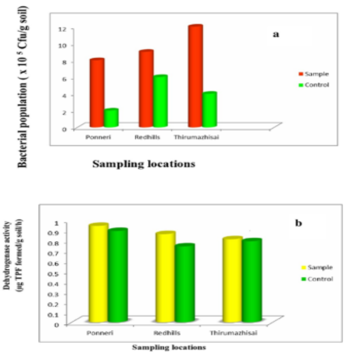


Figure 7. (a)Effect of biowaste compost amendment on bacterial population in the study area (Values represent mean of five replications), (b) Dehydrogenase enzyme activity in biowaste compost amended soil (Values represent mean of five replications)

The bacterial population was higher in soil samples from the Thirumazhisai region than it was in soil samples from Ponneri and Redhills. The results revealed that the microplastic content was less as this region was amended with biowaste compost for 4 years. The microplastic effect on soil and soil organisms depends on the type and concentration of plastics and exposure time (Guo *et al.*, 2020). Hitherto, only a limited number of studies have been carried out to examine the toxicology of microplastics to soil microorganisms (He *et al.*, 2018).

Conversely, some studies explained that soil microorganisms, including bacteria, are affected by exposure to high concentrations of microplastics (Bradney *et al.*, 2019). However, the bacterial population of soil samples taken from agricultural soils in the present study was not significantly impacted by microplastic pollution. The bacterial population in the soil taken from agricultural fields is comparable to that of the virgin soil collected 500 metres away from compost-amended soil. The cracks and cavities formed on the surfaces due to weathering and altered chemical properties provide a suitable condition for the colonization of various microorganisms (Zhang *et al.*, 2019). Some studies explained that other toxic pollutants in soil are absorbed on the microplastics or within the plastic ecocorona (the bound form of organic material and contaminants) (Galloway *et al.*, 2017), which protect the soil biota from toxic pollutants (Du *et al*., 2020; Sarker *et al.*, 2020). However, whether the effect of microplastics on soil organisms is positive or negative needs to be investigated further.

Dehydrogenase, one of the most crucial hydrolases in microbial respiration which is present in all living microbial cells (Song *et al.*, 2019). In this study, it was found that soils amended with compost made from biowaste had higher levels of enzyme activity than control soils. According to previous studies, the addition of microplastic enhanced the soil's dehydrogenase enzyme activity (Yi *et al*., 2021; Kumar and Sheela 2023), which may be attributable to either an improvement in the habitat of the soil (Zhao *et al.*, 2021) or the adaptation of microorganisms to the microplastic amended environment (Yi *et al.*, 2021). Also, the study by (Kumar and Sheela 2021) demonstrated that microbial activity did not get influenced by microplastic addition due to plastic film mulching. As a result, the bacteria in the soil may get nutrients from the compost made from biowaste and grow. The increased dehydrogenase activity in the study area compared to that in the virgin soil may be caused by an increase in the microbial population.

The harmful impacts of microplastics on plants are still not thoroughly studied (Jiang *et al.*, 2019). The different kinds of microplastics have an impact on shoot and root length reduction (van Weert *et al.*, 2019) as well as seed germination (Bosker *et al.*, 2019). Additionally, the interaction of heavy metals and microplastics has an adverse impact on soil biodiversity and plant growth (Wang *et al.*, 2020).

In contrast to primary microplastics, ageing of microplastics does not have an adverse effect (Kokalj *et al.*, 2019). However, in the current study, samples were gathered from agricultural soils amended with biowaste compost. The microplastics in the compost amended soil might have undergone ageing process, thereby effectuating less toxicity to the soil bacterial population. Nonetheless, extensive field monitoring is required to evaluate the potentially toxic effects of microplastics to crop species at various growth stages in the biowaste compost amended soils. The entry of microplastics from the compost to the agroecosystem might be prevented by adopting proper solid waste treatment method. The plastic materials that are adherent to the waste should be properly removed before using it for the composting process so as to prevent microplastic pollution of the agroecosystem.

4. Conclusion

Microplastics in agricultural soils of Ponneri, Redhills, and Thirumazhisai in Thiruvallur district, Tamil Nadu, India, were studied as a result of biowaste compost addition. The microplastic content in the soil samples collected from Ponneri, Redhills, and Thirumazhisai ranged from 0.29±0.1–3.28±0.8, 0.42±0.1–1.83±0.2 and 0.36±0.2–1.82±0.2 g/kg soil, respectively. The agricultural soils of Ponneri encountered more microplastic content than other samples due to the long duration of biowaste compost amendment. In the study area, different fforms of microplastics, including fragment, fibre, and pellet, were studied. In the study area, the three colours of microplastics that were looked at were black, white, and red. Polypropylene was the primary polymer type identified in this study area. The biowaste compost amendment does not have a substantial effect on the soil bacterial population and microbial activity. The presence of less concentration of microplastics in the virgin soils collected near the compost-amended soil might be either due to plastic littering or transported from other places by the wind. However, extensive study is required to examine the sources and effects of microplastic pollution in agricultural soils. Studies are also required to look at how microplastic pollution affects the structure of microbial communities, the availability of nutrients to crops, the germination of seeds, and crop growth. Therefore, better plastic waste management may help to prevent the accumulation of microplastics in terrestrial ecosystems like agricultural soils.

Author Contributions

Sindujaa A.M. (PG Student) conducted the experiment and wrote the original draft. Dhinagaran G (Assistant Professor) and Merline Sheela A. (Assistant Professor) supervised the student and edited the manuscript.

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