MICROPLASTICS AS AN EMERGING POLLUTANT IN FARMLAND SOIL: AN IMPACT EVALUATION STUDY ON FARMLAND SOIL PROPERTIES AND TOXIC METAL AVAILABILITY

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ABSTRACT

Microplastics (MPs) are an emerging environmental issue that might endanger the health of agricultural soil once they reach the environment. Despite the fact that several research on the particular toxicity of micro - plastics (MPs) to species have been carried out, there is little information about the relationship between heavy metals and MPs and their possible impacts on soil health. This study examined the changes in soil characteristics for both normal soil and artificially simulated heavy metals (Cd, Cr, Pb, Ni, Zn and Cu) contaminated soil caused by five distinct MPs, including Polyethylene (PE), Polyethylene terephthalate (PET), Polystyrene Foam (PS), Polyamide (PA), and a combination of these four types of MPs, at two doses (0.2% and 1%; w/w), to evaluate the interaction. After 90 days of soil incubation, substantial changes were seen in the soil's pH, EC, dissolved organic carbon (DOC), organic matter (OM), Na, Ca, Mg, NO3-, PO43+, and NH4+, as well as in its bulk density, porosity, water absorption capacity (WAC), and the availability of toxic elements (Cd, Cr, Pb, Ni, Zn and Cu). Impacts were largely influenced by MPs type and dosage. According to the results, when the MPs dosage is large, heavy metal availability and soil physiochemical properties - aside from nutrition availability - are mostly influenced. Additionally, according to our research, the cooccurrence of MPs and heavy metals may alter soil fertility as well as microbial diversity and functions, thereby endangering the multifunctionality of soil ecosystems.

Keywords: *Microplastic, Heavy Metals, Soil Environment, Vector Potentiality*

1. INTRODUCTION

Plastics, the synthetic polymers that is used largely indiscriminately in the modern world due to their low production cost, lightweight, elasticity, and durability properties (Naik et al., 2019). Since the 1950, the worldwide plastic production dramatically increased and the predicted total manufactured plastics was 348 million metric tonnes in 2050 with an annual increase of 33 billion tones globally (Tiseo, 2022). Polyethylene (PE), Polystyrene (PS), Polypropylene (PP), Polyethylene Terephthalate (PET), and Polyvinylchloride (PVC) are the most commonly produced and used plastic polymers (Geyer et al., 2017). Due to durability, unsustainable use, inadequate waste management, and low recycling rates, the plastics having a tendency to accumulate substantially in natural ecosystems (Barnes et al., 2009). Around 20% of plastics are recycled, whereas the existing 80% are ultimately gathered in different environmental matrix such as soil and water bodies (Letcher, 2020). The manufactured plastic particles or either breakdown of larger plastic items introduces an emerging contaminant into the environment called "microplastics" (longest dimension <5mm) (Lusher, 2017) have received scientific concern due to their pollution and risk into the soil, air, water ecosystem. Since the majority of plastic debris is generated and released on land, soils can act as a significant long-term sink for microplastics particles (Kawecki and Nowack, 2019). Urban and farmland soil are thought to be susceptible to microplastics emissions because they constitute the hub of human activity and, hence the channels for microplastics input (Fakour et al., 2021). According to reports, microplastics had contaminated 90% of the soil in the swiss floodplains (Scheurer and Bigalke, 2018). Numerous studies revealed microplastics in soil, particularly in farmland, 12-117 items/m2 (Fakour et al., 2021), 78.00±12.91 items/kg (Liu et al., 2018), 4.3×10 to 6.2×105 particles/kg (Zhou et al., 2019). Microplastics may enter the soil from a variety of sources, including compost, wastewater irrigation, sludge, plastic mulching, surface runoff, and atmospheric deposition (He et al., 2018; Feng et al., 2022). As a result, microplastics in farmland soil can adversely affect the soil ecosystem (Ai et al., 2022). When entering the soil, microplastics will change soil physiochemical properties (Feng et al., 2022), ecosystem functioning, and microbial population either directly or indirectly (Ya et al., 2021). Several studies reported that the soil Ph (Yang et al., 2021), soil structure (Wan et al., 2019), and soil fertility (Liu et al., 2017) can be changed by microplastics. Therefore, buildup of microplastics in farmland soil can negatively impact the health and functioning of soil ecosystems and ultimately pose hazards to the safety of the food chain (Mateos-Cárdenas et al., 2021). According to Rillig 2018, this new environmental anthropogenic stressor not only directly harms soil organisms but also has the potential to synergistically pollute the environment with other pollutants like heavy metals. Recent research suggests that because of their tiny size, high hydrophobicity, and greater surface area to volume ratio, microplastics are capable of absorbing organic pollutants and heavy metals on their surfaces under a variety of environmental conditions (Zhou et al., 2019). Soil health and agro-ecosystem has potential threat due to exposing of MPs and heavy metals (HMs) (Zhou et al., 2019). Several research found that MPs in agro-ecosystem could alter the bio-availability and characteristics of MHs (As, Cd, Cr, Ni, Cu, Pb, and Zn) (Medyńska-Juraszek and Jadhav, 2022). For example, microplastics enhance Cd toxicity in earthworms by increasing bioavailability (Zhou et al., 2020). In addition, microplastics and soil contaminants like Cd and nano-ZnO alter symbiotic fungi and plant growth due to microplastics enhance the availability of these elements, thereby threatened soil biodiversity and agroecosystems (Wang et al., 2020). However, there are significant knowledge gaps regarding the relationship between changes in soil properties under microplastics co-occurring with other heavy metals for understanding ecological effect on soil (Feng et al., 2022). Numerous studies have reported the microplastics abundance in freshwater or marine ecosystems (Liu et al., 2018; Ghosh et al., 2021). According to Horton et al., 2017, the majority of the plastic garbage in fresh and marine water environment derived from the land-based sources. However, knowledge on microplastics occurrence, and their fate in terrestrial environment is largely unexplored (He et al., 2018). Moreover, it is crucial to focus on the knowledge gap on microplastics presence and impact on terrestrial environment, especially in soil environment (Zhang et al., 2018). Consequently, studies on MP contamination in farming soil is a matter of concern. Therefore, the objective of this study was to assess the impact of MPs on soil physicochemical properties and toxic metals availability in contaminated and without contaminated agricultural soils.

2. MATERIALS AND METHODS

3. Microplastic Preparation

In this study, different types of plastic products were used as the sources of different types of microplastic. This study used plastic bottle, polyethylene paper, foam and nylon as the sources of Polyethylene terephthalate (PET), Polyethylene (PE), Polystyrene Foam (PS) and Polyamide (PA) respectively. Initially plastics items were cut into smaller pieces, less than 5 mm in diameter, in order to get the polymers from those things and to ensure the desired size is obtained, the smaller pieces were subsequently passed through a 5mm sieve. The small bits were first rinsed with water, and secondly wash with double-distilled water. Finally, they were cleaned with 0.1 N HNO_3 to eliminate any remaining organic material from their surfaces. After washing, they were thoroughly dried at 80 °C in a Labtech LDO-150F oven (Korea), and then cooled to room temperature and then were ready to use for the study purpose.

4. Soil Preparation and Experiment Set-up

The test soil is a sandy clay loam soil (sand 57%, silt 22%, clay 21%) taken from a nearby vegetable farmland, located at Abdulpur Village, Jashore District, Bangladesh (23º 13' 43.23" N, 89º 8' 53.14" E). The soil was collected from the top layer (0-20 cm) of the land. The soil was air-dried, grounded and passed through a 2 mm sieve for soil incubation experiments. Finally, two different types of groups were created, one is normal soil (without contaminated) and other is artificially contaminated soil with heavy metals (contaminated) by adding the metals salt solution into the soil and then kept the soil in dark for 7 days. After 7 days the soil was then dried, grounded and sieved as explained previously. This study conducted a three factorial pot experiment on 10 August, 2022. Five different types of microplastics were used for this test and those are Polyethylene terephthalate (PET), Polyethylene (PE), Polystyrene Foam (PS) and Polyamide (PA). Five different microplastics particle were then prepared with four individual component and a mix of the four of them. Thus, the five different MPs stands for PE, PET, PS, PA and Mix MPs. These MPs were then added to both normal soil (without contaminated), and artificially contaminated soil (contaminated) at two different doses (0.2% and 1%, w/w) and a control study for both without contaminated and contaminated soil. Total of 22 pots (16 for without contaminated and 16 for contaminated soil) were then filled with 200g soil-MPs mixtures. Throughout the whole incubation, soil moisture was kept at 30% of its maximal water holding capacity. To prevent water from evaporating, Parafilm® was used to seal the cup's top. All the cups were placed randomly and kept in darkness at 25 ± 0.5 ℃. Following 90 days of incubation, soil was taken for chemical analysis. Triplicate experiments were conducted for this study, where average value was used for results.

5. Analysis of soil properties

Analytical grade chemicals and reagents were used throughout the investigation. In a soil water suspension (soil-water ratio 1:2.5), soil pH was determined by using PH meter (Milwaukee pH56 Martini Pocket pH meter, Romania). The molybdenum-antimony anti-colorimetric technique was used to extract the soil's available P using ammonium fluoride-hydrochloric acid (Bray-1), and the results were then measured using an ultraviolet spectrophotometer (HACH DR 3900) at 700 nm. 2 mol/L KCl was used to extract the nitrogen from the soil, and an ultraviolet spectrophotometer was used to measure the amounts of NH_4^+ and NO_3^-. The extracted solution was evaluated at 220 nm and 275 nm for the analysis of NO_3^-, and at 625 nm for the measurement of NH_4^+. Soil OC and OM was determined by using Walkley – Black titrimetric method. Following Allen et al., (1986) instructions soil samples were digested using the tri-acid combination [HNO_3 (69%): H_2SO_4 (98%): $HClO_4$ (70%) = 5:1:1]. A 250 mL conical flask was filled with precisely 1.00 g of crushed material, which was then digested with 15 mL of the tri-acid solution at 180–200°C until a clear solution was obtained. The digested solution was then cooled to a temperature of around 25°C, filtered using Whatman 41 paper, and diluted to a volume of 100 mL with double-distilled water. Blank samples were also prepared using a similar process. Graphite furnace, hydride initiator, and air-acetylene flame Atomic-absorption-spectrophotometer (AAS) (Model: AA-7000, SHIMADZU, Japan) were used to measure the concentration of Cd, Cr, Pb, Ni, Cu, Zn, Na, Ca, and Mg in the samples.

6. Adsorption Isotherm and Kinetic Experiments

Adsorption isotherm studies were carried out into 250 mL dye solutions of varied dye concentrations (5 to 70 mg/L), at pH 2, where 10 g/L adsorbent dose (PETWBC and RSBC) was added and stirred the solution at 200 rpm with ambient temperature for 150 min. While kinetics experiments were run in 300 mL dye solution at a fixed concentration (20 mg/L) and kept the other condition constant, then samples were taken out after following time intervals 1, 5, 7, 10, 15, 20, 30, 60, 90, 120, 150, and 180 min, filtered, and analyzed. This study applied Langmuir and Freundlich for equilibrium data modelling while pseudo-first-order and pseudo-second-order were used for kinetic modelling, detailed presented in Table 1.

7. Statistical Analysis

SPSS V.16.0 (SPSS, USA) and Microsoft Office LTSC Professional Plus 2021 were used in this study's statistical analysis. Calculations were made about the availability of heavy metal contents in soil samples as well as the available soil property contents.

8. RESULTS AND DISCUSSION

9. Effects of MPs on soil physicochemical properties

pH is considered as a most vital parameters in soil because at optimum pH enhanced essential nutrients for plants. The level of pH in soil is significantly affected by MPs abundance, types, polymers and duration of incubation (Zhao et al., 2019). This study result shows that the PS increase soil pH with increasing MPs dose (0.2-1%) for contaminated (5.97-6.85) and without contaminated soil (6.42-6.93) due to increases of soil aeration and porosity or leaching of chemical additives (Kim et al., 2020). Qi et al. (2020) found that MPs increases soil pH. Conversely, other MPs (PE, PET, PA, and mixed) reduces the soil pH for both contaminated and without contaminated soil might be releasing of organic acid from MPs through mineralization (Boots et al., 2019). Feng et al. (2022) reveals that PE, PS, PA, and PBS MPs reduce the soil pH. Electrical conductivity (EC) is very vital for soil health, elevated and lower level of EC reduces nutrient availability and accessibility for plant. MPs types and abundance can change the EC value of soil (Afrin et al., 2020). This study shows that PE, PS, PA and Mix (MPs) increases the soil EC value at lower dose (0.2%, w/w) but decreases at higher dose (1%, w/w) in both contaminated and without contaminated soil (Table 1). This table shows that the lower dose of PE is increasing the EC value of the soil at a significant rate at both instances. Additionally, in term of PET the soil EC value is decreasing with the increase of dose for both contaminated and without contaminated soil (Table 1). MPs alter soil porosity and bulk density, which are two contributing elements that influence soil EC (Kim et al., 2020). Soil organic carbon and organic matter significantly influences for soil fertility, which reduces soil erosion and nutrient leaching rates parallel increases soil aeration, water drainage, and retention. Experimental results shows that all MPs types (PE, PET, PS, PA, and mixed) changes the contents of OC and OM percentage in contaminated (OC=0.468-0.265%, and OM=1.001-0.840%) and without contaminated (OC= 0.446-0.375%, and OM= 0.105-0.593%) soil at low dose (0.20%) than higher dose (1%). More specifically, mixed MPs shows the highest reduction rate for both soil (Table 1). MPs alter the structure of microorganism community and their activity which influences the decomposition and conversion of organic materials (Liu et al., 2017). Zhang et al. (2022) reveal that MPs gathering in agricultural soil could cover soil organic carbon storage. Liu et al. (2017) explore that MPs have significant negative effects on SOC and SOM, respectively. Dong et al. (2021) found that Polytetrafluorethylene and Polystyrene reduces about 34.3% and 25.8%, SOM, respectively.

Table 1: Effects of MPs on soil physicochemical parameters in both contaminated and without contaminated soil

MPs Type	***MPs Dose (w/w)***	***pH***		***EC (mS/cm)***		***OC (%)***		***OM (%)***	
		Without Contaminated Soil	**Contaminated Soil**	**Without Contaminated Soil**	**Contaminated Soil**	**Without Contaminated Soil**	**Contaminated Soil**	**Without Contaminated Soil**	**Contaminated Soil**
	Control	6.42	5.97	0.4432	0.4432	0.531	0.531	1.191	1.191
PE	***0.20 %***	6.31	5.9	0.5733	0.5733	0.469	0.447	1.051	1.001

	1%	6.21	5.92	0.4195	0.4195	0.431	0.5	0.966	1.121
PET	***0.20 %***	6.14	5.8	0.4276	0.4276	0.391	0.453	0.875	1.015
	1%	6.08	5.9	0.4193	0.4193	0.469	0.406	1.051	0.91
PS	***0.20 %***	6.76	6.22	0.476	0.476	0.447	0.469	1.001	1.051
	1%	7.03	6.85	0.4035	0.4035	0.422	0.517	0.945	1.158
PA	***0.20 %***	6.1	5.6	0.4718	0.4718	0.406	0.5	0.91	1.121
	1%	6.33	5.91	0.3998	0.3998	0.484	0.203	1.085	0.455
Mix	***0.20 %***	6.4	5.8	0.4477	0.4477	0.265	0.375	0.594	0.84
	1%	6.21	5.86	0.4117	0.4117	0.432	0.469	0.968	1.051

MPs Type	**MPs Dose (w/w)**	***Bulk (g/mL)***	***Density***	***Porosity (%)***		***Water Absorbtion Capasity (%)***	
		Without Contaminated Soil	**Contaminated Soil**	**Without Contaminated Soil**	**Contaminated Soil**	**Without Contaminated Soil**	**Contaminated Soil**
	Control	1.25	1.3	50	48	80	75
PE	***0.20 %***	1.063	1.07	47.37	47.03	77	72
	1%	1.122	1.15	44.44	43.07	72	69
PET	***0.20 %***	1.092	1.099	49.91	49.59	68	64
	1%	1.263	1.25	43.75	42.66	60	59
PS	***0.20 %***	1.01	1.03	40	38.81	65	62
	1%	1.11	1.13	34.07	32.87	59	57
PA	***0.20 %***	1.122	1.14	48.99	48.18	73	67
	1%	1.195	1.2	46.75	45.45	65	62
Mix	***0.20 %***	1.015	1.03	44.72	43.91	70	66
	1%	1.13	1.17	38.47	36.29	62	60

Soil bulk density represents the soil's capacity to support structures, convey water and solutes, and aerate the soil. MPs present in soil influence the change in bulk density. This study found, bulk density decreases at a larger rate at lower dose than at higher dose for contaminated (1.3-1.03 g/cm3) and without contaminated soil (1.25-1.01 g/cm3) (Table 1). A study by Qi et al. (2020) also found similar kind of change in the presence of MPs. Soil porosity enhances the availability and mobility of water and air within the soil environment. The percentage of pore space in experimental soil gradually reduces with increasing MPs dose for both contaminated (48-32%), and without contaminated soil (50-34%) through reducing the soil pore numbers and size (Guo et al., 2022) among the all MPs, PS shows highest effect. de Souza Machado et al. (2018) also discovered similar type of changes. Soil water holding (WHC) capacity defines the soil productivity. Soil with high water holding capacity improves the crop yield. But presence of MPs changes the WHC for both contaminated (75-59%), and without contaminated soil (80-62%) (Table 1) due to altering the soil texture and organic matter. This study has found that, the water holding capacity is decreasing at a significant rate with the change in MPs doses (Zhao et al., 2019). Wang et al. (2023) found that high concentration of MPs reduces the soil water holding capacity.

10. Effects of MPs on Soil Nutrients availability

Soil micro and macro nutrients maintain soil fertility and it's highly needed for plants growth, development and production. Too much and too low nutrients reduces soil quality and agricultural production (Kumar et al., 2021). The descending order of MPs for soil nutrients (NO3, PO4, NH4, Na, Ca, and Mg) are mixed MPs > PET > PS > PA > PE and mixed MPs > PS > PA > PET > PE for contaminated and without contaminated soil, respectively. Sodium (Na) helps to keep the soil fertile by marinating basal performance and also helps to plants for utilizing water efficiently through controlling the osmotic pressure of the cells (Kronzucker et al., 2013). The experimental study shows that initial doses of MPs (0.20%) decrease the Na contents from contaminated (1-24%) and without contaminated soil (17-26%) (Fig 1a-b). Calcium (Ca) regulates cell wall structure and membranes additionally it plays a vital role for balancing organic acid and enzyme systems (White and Broadley, 2003). The concentration of Ca in soil significantly reduces in both soil (contaminated =4-22%, and without contaminated = 3-41%) (Fig 1c-d). Magnesium (mg) assists plant physiology and biochemical activities, it acts as a key element for plant growth, development and protecting agent for reducing abiotic stress (Senbayram et al., 2015). Abundance of MPs in agricultural soil slightly decline the Mg contents (Contaminated = 2-7%, and without contaminated = 0.3-4.76%) (Fig 1e-f). MPs directly and indirectly alter the soil physicochemical properties (pH, temperature, moisture, OC, OM, structure, texture, etc.) and microbial activities, which enhances soil permeability, nutrient leaching rate, and availability of elemental concentration (Wang et al., 2020).

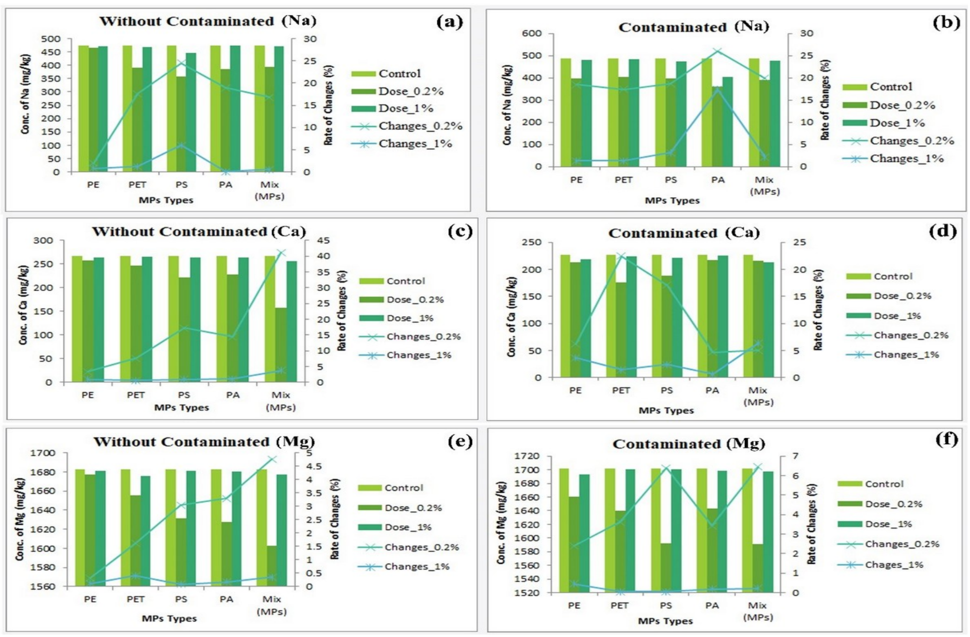

Figure 1. Effects of MPs on soil nutrients availability in both without contaminated and contaminated soil, (a-b) Na; (c-d) Ca; (e-f) Mg; respectively

Plants uptake inorganic nitrogen form the soil, mostly as NH4+ and NO3- that's are significantly stimulate plants growth (Hachiya and Sakakibara, 2017). The concentration of NH4+ (Contaminated = 8-50%, and without contaminated = 8-48%) (Fig 2e-f), and NO3- (Contaminated = 9-45%, and without contaminated = 0.72-19%) (Fig 2a-b) are reduces from soil by MPs due to leaching from agro-ecosystems, altering the soil surface functional groups, and hindering the actions of main enzymes in the soil nitrogen cycle (Liu et al., 2022). Zhu et al. (2022) found that MPs reduced NO3--N concentration by up to 91%. The contents of phosphate in soil are reduces (without Contaminated = 17-11.39 mg/kg, and contaminated = 19.5-13.67 mg/kg) (Fig 2c-d), might be constraining soil enzyme actions. Li and Liu (2022) exhibited that the concentration of phosphate in soil reduces from 122.61 mg/kg to 63.43 mg/kg by MPs.

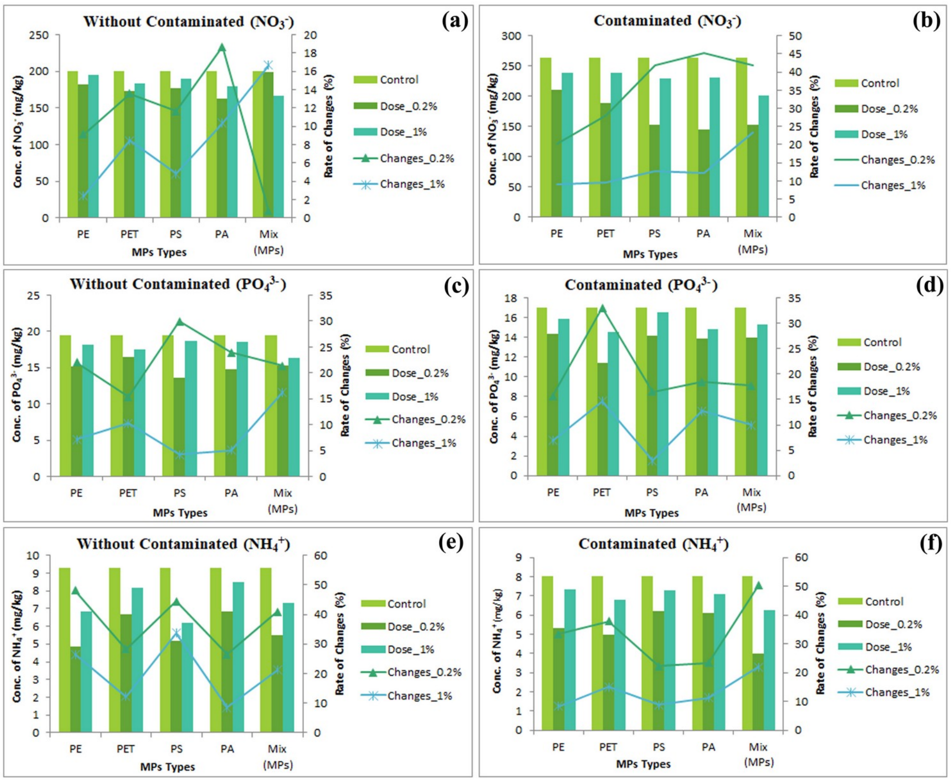

Figure 2. Effects of MPs on soil nutrients availability in both without contaminated and contaminated soil, (a-b) NO_3^-; (c-d) PO_4^{3-}; (e-f) NH_4^+; respectively

11. Effects of MPs on Soil metals availability

MPs act as vector that carries potential hazardous elements (eg. heavy metals) from the surrounding environment, consequently it declines the soil quality by triggering the synergistic effect of MPs-HMs (Liao et al., 2023) where MPs influence the relocation and alteration of HMs through adsorption, precipitation or modifying the physiochemical parameters of soil (Medyńska-Juraszek and Jadhav, 2022). This study findings shows that MPs significantly adsorb the HMs from the experimental soil and the descending order of HMs were Pb > Zn > Cd > Cr > Cu > Ni (Fig. 3 & 4). The distinct properties of MPs including small particle size, bulky surface area, lipophilic nature, specific morphological feature directly involved reducing the bioavailability of HMs, while MPs indirectly decreases HMs availability by altering the soil properties such physical, chemical and biological properties (Medyńska-Juraszek and Jadhav, 2022; Liao et al., 2023). Yuan et al. (2020) found that MPs reduces HMs availability and the following order was Pb > Cu > Cd > Ni (Fig. 2). Feng et al. (2022) also found that MPs significantly adsorb Zn and Pb from agricultural soil.

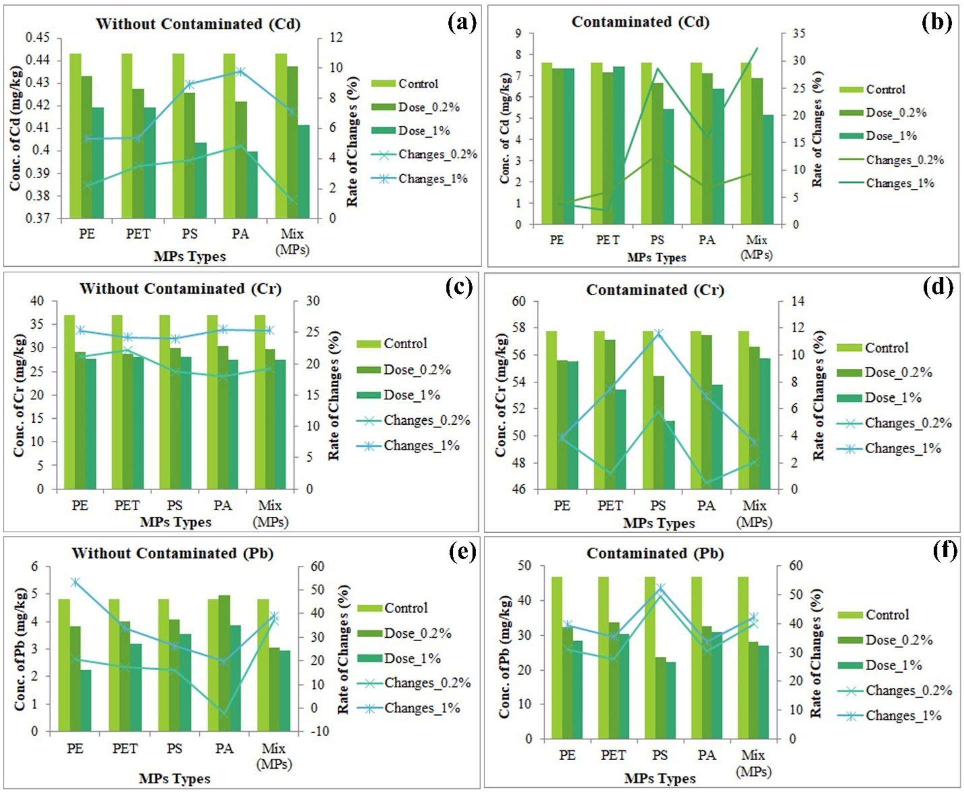

Fig. 3. Effects of MPs on soil metals availability in both without contaminated and contaminated soil, (a-b) Cd; (c-d) Cr; (e-f) Pb; respectively

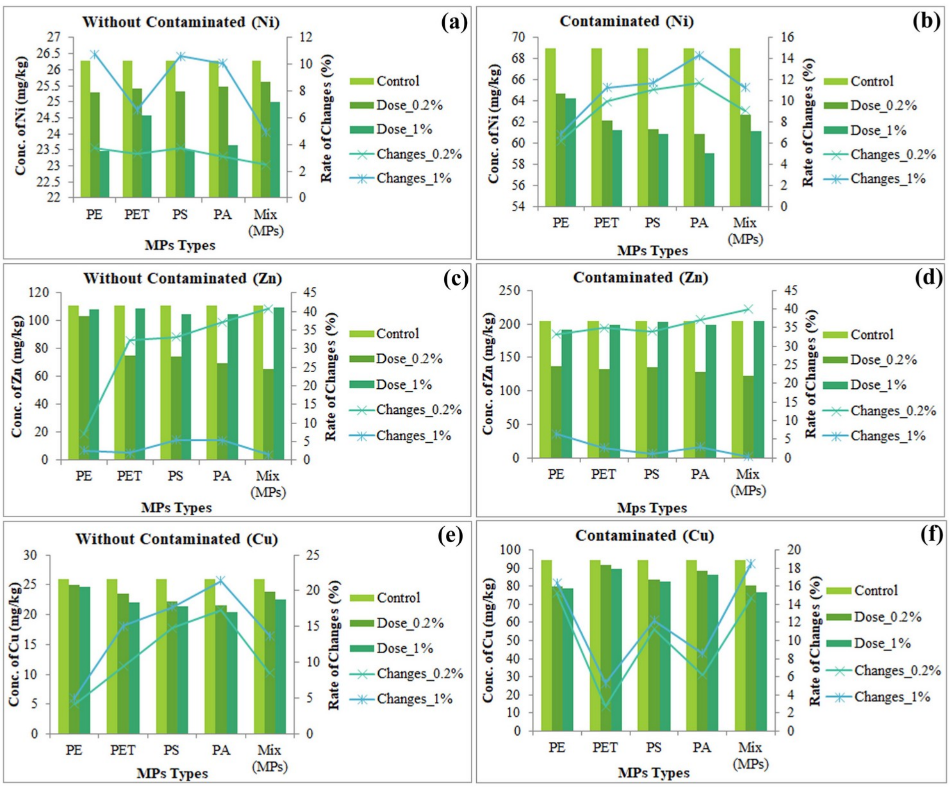

Fig. 4. Effects of MPs on soil metals availability in both without contaminated and contaminated soil, (a-b) Ni; (c-d) Zn; (e-f) Cu; respectively

12.CONCLUSIONS

After 90-day soil incubation experiment, this study found that soil chemical properties (pH, EC, OC, OM) and physical properties (bulk density, porosity water absorption capacity) are changing significantly with dose variation, beside soil nutrient (Na, Ca, Mg, NO3-, PO43-, NH4+-N) availability are mostly decreasing more at lower dose while higher dose poses negligible changes. The bio availability of heavy metals (Cd, Cr, Pb, Ni, Zn and Cu) are decreasing with the dose increases, exception for Zn. Typically, all the effects varied with MPs type and applied dose. Except for soil nutrients, higher MPs doses largely exhibited a substantial influence. Among the MPs types, PS exerted the greatest impact whereas PE had the least impact for changing soil properties. This study reveals that, MPs directly or indirectly changes the availability of HMs, decreases the soil fertility by altering soil physicochemical properties that's related to nutrient cycle (Carbon, nitrogen, and Phosphorous cycle), triggering possible environmental risks. Further studies are necessary to investigate the interaction mode of MPs with HMs and other physicochemical parameters and finally understand their probable effects on living organisms and soil health.

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