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Plastic granules and their impact on the concentration of some mineral elements and conductivity in the soil

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ABSTRACT

The current study was conducted in the plastic houses of the (University of Mosul - College of Education for Pure Sciences - Department of Biology), for the academic year 2024 for study the effect of soil pollution with granules of five types of plastic. The results showed that treating the soil with plastic granules of type C at a concentration of 50 and 100 gm/5 kg soil led to a significant decrease in the concentration of both nitrogen, phosphorus and calcium which reached (0.0049, 0.0019), (0.1248, 0.0906) and (0.008, 0.008) % respectively compared to their concentration in the comparison treatment, which recorded (0.0059, 0.1959 and 0.0200) %, respectively. When the soil was treated with PET plastic granules, the phosphorus concentration likewise significantly decreased, reaching (0.0632) % as opposed to (0.1959) % in the comparator treatment. Additionally, there was a notable drop in conductivity, which reached (0.714) % when treated with PVC at a concentration of 100 gm/5 kg soil, and $CaCO_3$ concentration when treated with LDPE, which recorded (17.5) %, in comparison to their concentrations in the comparison soil, which recorded 1.836 and 20%, respectively.

الحبيبات البلاستيكية وتأثيرها على تركيز بعض العناصر المعدنية والتوصيلية الكهربائية في التربة

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الخلاصة:

أُجريت الدراسة الحالية في البيوت البلاستيكية التابعة لـــ(جامعة الموصل – كلية التربية للعلوم الصرفة – قسم علوم الحياة) للعام الدراسي 2024، لدراسة تأثير تلوث التربة بحبيبات خمسة أنواع من البلاستيك. أظهرت النتائج أن معاملة التربة بحبيبات البلاستيك من النوع C بتركيز 50 و100 غم/5 كغ تربة أدت إلى انخفاض معنوي في تركيز كل من النيتروجين، الفوسفور، والكالسيوم، حيث بلغت (0.0049، 0.0019)، (0.1248، 0.0906)، و(0.008، 0.008) % على التوالي، مقارنة بتركيزها في المعاملة المقارنة التي سجلت (0.0059، 0.1959، و0.0200) % على التوالي. عند معاملة التربة بحبيبات البلاستيك من نوع PET، انخفض تركيز الفوسفور أيضًا بشكل معنوي، حيث بلغ (0.0632) %

مقارنة بـــ (0.1959) % في المعاملة المقارنة. بالإضافة إلى ذلك، لوحظ انخفاض ملحوظ في التوصيلية الكهربائية، حيث بلغت (0.714) % عند المعاملة ببولي فينيل كلوريد (PVC) بتركيز 100 غم/5 كغ تربة، وتركيز كربونات الكالســـيوم ($CaCO_3$) عند المعاملة ببولي إيثيلين منخفض الكثافة (LDPE)، حيث ســـجل (17.5) %، مقارنة بتركيزها في التربة المقارنة التي سجلت 1.836 و20% على التوالي.

الكلمات المفتاحية: الحبيبات البلاستيكية، العناصر المعدنية، التوصيل، التلوث، التربة.

Introduction

In recent years, environmental scientists have focused on microplastic contamination in soil as a persistent contaminant with serious consequences for soil ecology and agricultural production, with potentially major effects on soil ecosystem functioning, microplastics can alter the physical and biochemical characteristics of soil and aid in the movement of other contaminants within it[1]. The development of plastics is a huge industrial innovation, and as production, technology has advanced, so too have the benefits of plastics in terms of economy, efficiency, and substitute capability. There are several types of plastic products that have become an essential part of our daily lives. Statistics show that 8.3 billion tons of plastic have been produced worldwide in total[2]. But only around 20% of plastic is recycled; the other 80% eventually ends up in the environment, such as soil, rivers, and the ocean[3].

Plastics are polymers composed of a variety of synthetic or semi-synthetic organic compounds, Polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polyamide (PA) are among the synthetic or semi-synthetic organic chemicals that make up plastics. Plastics' low cost, superior flexibility, and durability have made them widely used in a variety of industries, including industry, agriculture, medicine, and many more [1]. Numerous agricultural activities, including the use of plastic mulch [4], the dispersal of sewage sludge [5], and land irrigation [6], contribute to the accumulation of microplastics in ecosystems. Additionally, when solid waste is collected, processed, transported, and buried, secondary microplastics are

discharged. Furthermore, microplastics can move from land to aquatic ecosystems and vice versa, and wind plays a role in their spread. The usage of agricultural plastics, including as plastic sheeting, feed bins, and tunnels, is also linked to secondary microplastic pollution. Additional plastics used in agriculture, such as nets, containers, and packaging, may contribute to soil microplastic pollution. Furthermore, plastic compounds in land are more affected by sunlight-induced disintegration than those in water [7]. This makes them more impactful. Thus, the purpose of this study is to investigate how plastic granules affect specific soil characteristics. Plastics widely distributed in agricultural soil can affect the physical and chemical properties of soil, reduce soil fertility, and even change the microbial community in soil, affecting soil quality and nutrient cycling.

Materials and methods:

1- Soil preparation:

The soil of Al-Abbasiya village area located in Nineveh Governorate was selected. Surface soil samples were taken from a depth of (0-30) cm, air dried, smoothed and passed through a sieve with a diameter of (2 mm) holes.

2- Soil Treatment:

Plastic house experiments were conducted to study the effect of plastic granules pollution on soil properties. The treatments used in this study included (5) types of plastic granules with two concentrations for each type (50 and 100 g / 5 kg soil). The plastic samples specified in the study were taken from agents and offices selling raw plastic granules from local markets in the Kurdistan Region of Iraq, namely:

Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polyvinyl Chloride (PVC), Carbon Polyethylene (C). In addition to the control treatment, with three replicates for each treatment, and the addition was made according to the type and concentration of plastic

granules, each separately according to the treatment, to the soil; as they were mixed outside the pots and then placed in the pots; to ensure that they were mixed well, and the experiment was carried out using plastic pots with a diameter of (25) cm and a height of (20) cm, the capacity of each pot (5) kg of soil.

3- Cultivation and irrigation:

Basil seeds (*Ocimum basilicum*) were obtained from local markets in Mosul city and the seeds were planted on 3/10/2024 at a rate of (10) seeds/pot. It was taken into account that the distances between the seeds were equal for each plant. The pots were placed randomly under the conditions of the plastic house. The pots were irrigated with running water. After (10) days of planting, the number of seedlings was reduced to (5) seedlings in each pot. After (80) days from the date of planting, the plants were harvested at a rate of (3) replicates for each treatment.

4- Studied characteristics:

The necessary analyses of soil samples were conducted in the laboratories of the Department of Biology / College of Education for Pure Sciences, and the laboratories of the Department of Soil Sciences / College of Agriculture and Forestry / University of Mosul as follows:

The Electrical conductivity (EC) was measured according to the methods mentioned by [8], the concentration of calcium carbonate according to the method of [9] and both calcium and nitrogen according to the microkjeldahl method, and the concentration of phosphorus using a spectrophotometer according to the method of [10].

5- Statistical analysis:

The experiments were designed and statistically analyzed using the factorial experiment according to the completely randomized design (C.R.D) in the

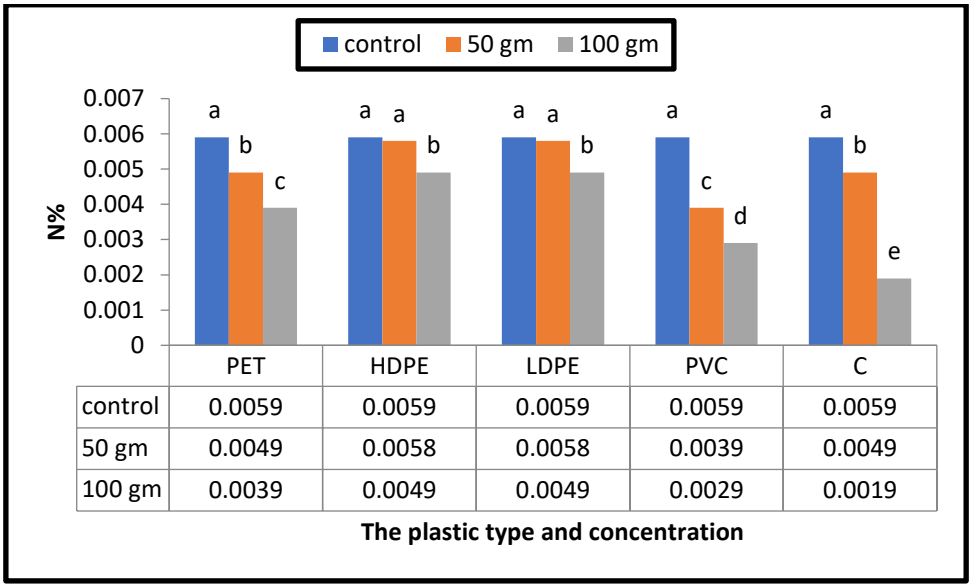
factorial experiments [11], and the significant differences in the treatment rates were compared using Duncan's New Multiple Range Test.

Results and Discussion:

Nitrogen (N):

These granules were chosen because they represent one of the causes of pollution in the environment. As illustrated in Figure 1, the nitrogen concentration in the soil significantly decreased after being treated with five different types of plastic granules (PET, HDPE, LDPE, PVC, and C) at two concentrations (50 and 100) gm/5 kg soil for each type. The nitrogen concentrations recorded were (0.0049, 0.0039), (0.0058, 0.0049), (0.0039, 0.0029) and (0.0049 and 0.0019) %, respectively. When type C was added to the soil at a concentration of 100 gm/ kg of soil, the lowest value was obtained (0.0019) %, which was lower than the comparison treatment's (0.0059%) %. However, it was shown that soils treated with HDPE and LDPE plastic granules had the highest nitrogen concentration in soil tests, reaching 0.0058 % at a concentration of 50 gm / kg of soil. According to [12], the drop in nitrogen content can be the result of a higher concentration of microplastics in the soil, which lowers soil enzyme activity and restricts microbial nitrogen transformations. Nitrogen deficit is exacerbated by the presence of low-density polyethylene microplastics [13]. In comparison to nutrients like potassium, phosphorus, or nitrogen, microplastics are more likely to be absorbed by mechanical transport. Additionally, the nitrogen cycle and soil microbial activity may be impacted by the presence of microplastics [12]. Following their deposition in the soil's surface, microplastics are decomposed by UV radiation from the sun, as well as by elevated temperatures and oxygen availability [7] and [14], which affecting on the mineral elements' concentration However, it is reasonable to assume that altering the soil's structure and function by introducing microbes will have an impact on the diversity and makeup of the microbial community, particularly on root zone microbes like nitrogen fixers [15], which in

turn will alter the concentration of nitrogen. The spread of plastic compounds in the soil and under the influence of drought-wet cycles and biological changes [16] may cause changes in its physical and chemical properties, including carbon, nitrogen, phosphorus and pH content [17].

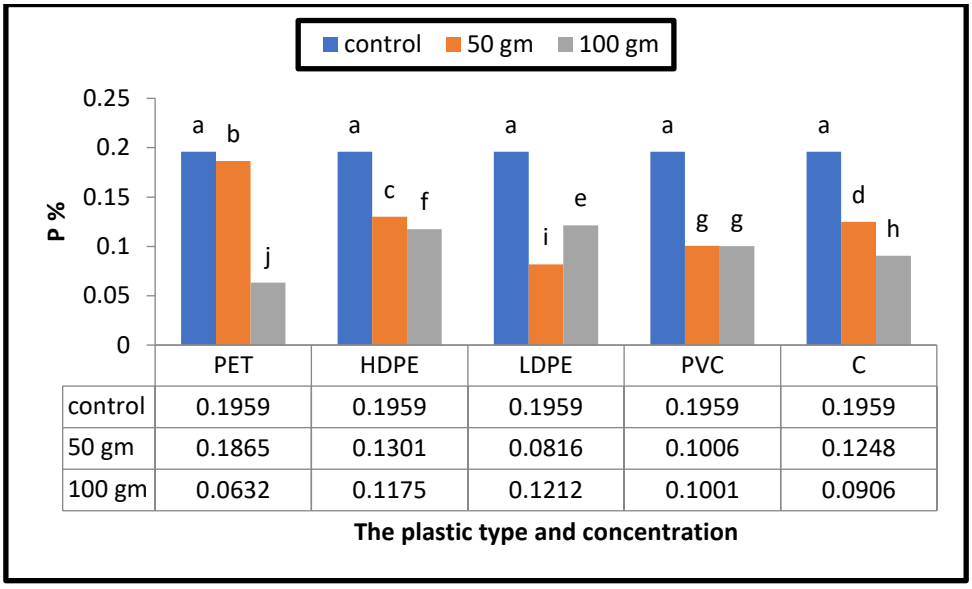


	PET	HDPE	LDPE	PVC	C
control	0.0059	0.0059	0.0059	0.0059	0.0059
50 gm	0.0049	0.0058	0.0058	0.0039	0.0049
100 gm	0.0039	0.0049	0.0049	0.0029	0.0019

Figure (1) Effect of treatment with different types of plastic and two concentrations of each type on nitrogen concentration (%) in the soil.

Phosphorus (P):

Figure (2) shows a significant decrease in the concentration of phosphorus in the soils treated with different plastic granules. It recorded (0.1865, 0.0632), (0.1301, 0.1175), (0.0816, 0.1212), (0.1006, 0.1001) and (0.1248, 0.0906) % when treating the soil with five types of plastic granules, which are (PET, HDPE, LDPE, PVC and C) at two concentrations (50 and 100) grams/5 kg of soil for each type, respectively. The lowest value appeared when treating the soil with PET plastic granules at a concentration of (100) gm/5 kg of soil, reaching (0.0632) %. The highest value also appeared when treating with the same type, reaching (0.1865), but at a concentration of (50) gm/5 kg of soil, compared to the comparison treatment, which recorded (0.1959) %. Microplastics have been observed to cause discoloration of plants, possibly due to poor nutrient uptake, with brown spots on leaves. Brown spots often indicate phosphorus deficiency [18].



	PET	HDPE	LDPE	PVC	C
control	0.1959	0.1959	0.1959	0.1959	0.1959
50 gm	0.1865	0.1301	0.0816	0.1006	0.1248
100 gm	0.0632	0.1175	0.1212	0.1001	0.0906

Figure (2) Effect of treatment with different types of plastics and two concentrations of each type on the concentration of phosphorus (%) in the soil.

In addition, the molecular chain arrangement and functional group of plastics may affect their ability to absorb other compounds such as heavy metals or antibiotics, which may have an impact on soil properties and microbial activity, which may affect mineral concentrations. Studies have also revealed that certain types of polymers, such as polyethylene, polypropylene, and polyvinyl chloride, may have different adsorption capacities for certain compounds. For example, polystyrene had a higher adsorption capacity for polycyclic aromatic hydrocarbons compared to polyethylene terephthalate, polyvinyl chloride, polyethylene, or polypropylene, while polyethylene had a higher adsorption capacity for hydrophobic chemicals such as pesticides and solvents [19]. It affects the concentration of mineral elements. Another strong influence on the dynamics of the nutrient cycle in the soil is the presence of plastic materials [20]. They may reduce the soil content of available phosphorus, alkaline nitrogen, and available potassium [21], leading to a decrease in the concentration of mineral elements in the soil.

Calcium (Ca):

Figure (3) shows that treating the soil with plastic granules at two concentrations (50 and 100) gm/5 kg soil for each type and for the following types (PET, HDPE,

LDPE, PVC and C) led to a decrease in the concentration of calcium in the soil, which recorded (0.014, 0.012), (0.016, 0.014), (0.014, 0.012), (0.010, 0.008) and (0.008, 0.008) % respectively. The lowest value appeared when treating the soil with the PVC type at a concentration of (100) and the C type at a concentration of (50 and 100) gm/5 kg soil, as it reached (0.008) %, and the decrease here was significant compared to the comparison treatment, which recorded (0.02) %.

As a result of the impact of microplastics on soil water content, changes in soil water content may alleviate or exacerbate drought, which is expected to increase as a result of climate warming over the next few decades [22]. This in turn may affect mineral concentrations. Changes in soil structure that cause changes in soil hydrological dynamics caused by plastics of different concentrations, types, sizes and shapes may lead to unexpected effects [23]. In addition, the impact of microbial communities due to the presence of plastic materials affects biochemical transformations that affect the fate of nutrients such as mineralization or denitrification and the availability of nutrients [24]. In addition, plastic waste inhibits the growth of microorganisms important for soil activities and thus reduces soil nutrients, fertility and productivity [25]. According to some researchers, the impact of microplastics on soil biology is not only caused by the plastic particles themselves, but also by other materials such as plasticizers, stabilizers, flame retardants and other materials that can absorb some heavy metals and organic pollutants that can affect the soil [7], and all of these reasons can affect the concentration of mineral elements in the soil.

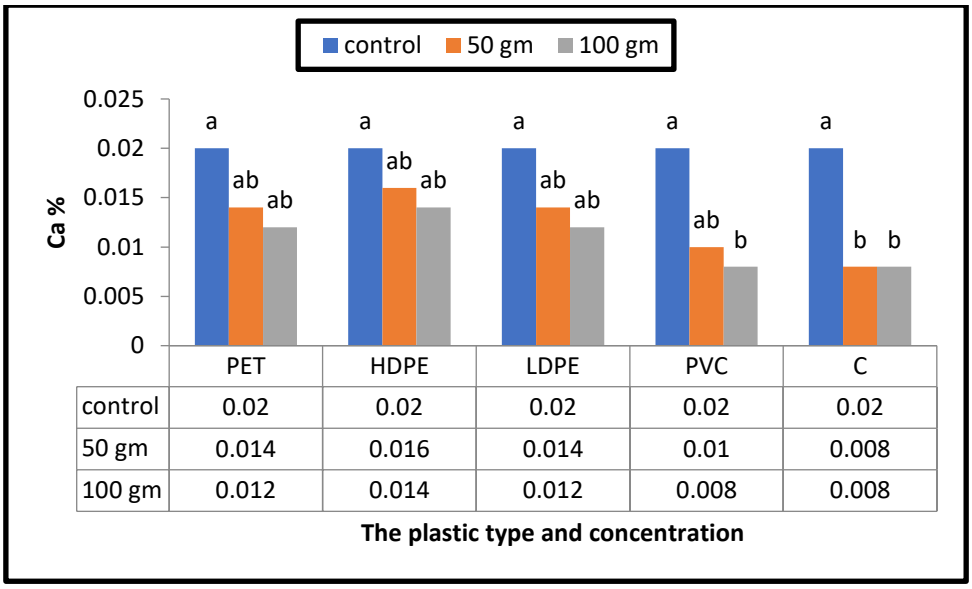


Figure (3) The effect of treatment with different types of plastic and two concentrations of each type on the concentration of calcium (%) in the soil.

Calcium carbonate ($CaCO_3$):

Figure (4) illustrate, treating the soil with plastic granules at two concentrations (50 and 100) gm/5 kg soil for each of the following types (PET, HDPE, LDPE, PVC and C) led to a significant increase in the concentration of calcium carbonate in the soil, which recorded (21.5, 27.5), (35, 30), (22.5, 17.5), (27, 28) and (33, 26) %, respectively. The lowest value of calcium carbonate appeared when treating the soil with the LDPE type at a concentration of (100) grams/5 kg soil, reaching (17.5) %, and the highest concentration appeared when treating with HDLE at a concentration of (50) gm/5 kg soil, reaching (35)% compared to the control treatment, which recorded (0.20)%.

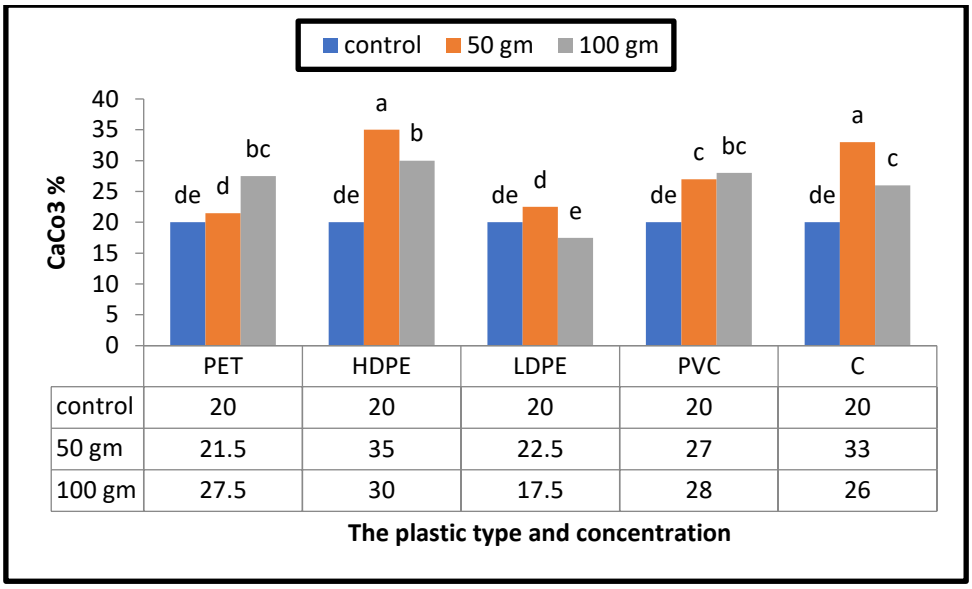


Figure (4) Effect of treatment with different types of plastic and two concentrations of each type on the concentration of calcium carbonate (%) in the soil.

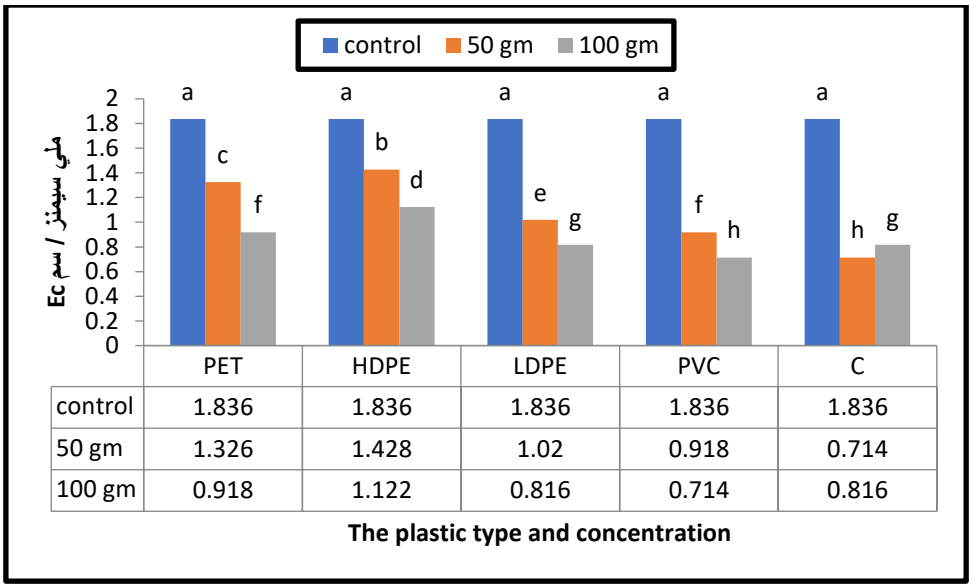
The accumulation of these plastic compounds causes soil deterioration and affects its properties in the long term, affecting both plants and microorganisms present in the soil. Microplastics can persist for long periods of time, once in the soil, interacting with soil particles, microorganisms, and plants in ways that can have significant impacts on the soil [26]. These effects depend on the type of particles [24]. In addition, the molecular chain arrangement and functional group of plastics may influence their ability to adsorb other compounds such as heavy metals or antibiotics, which may have an impact on soil properties and microbial activity [19]. [27], illustrate that, changes in the physical and chemical properties of soil, such as porosity, enzyme activity, microbiological activity, and plant growth, are affected by microplastics. In addition, microplastics play an important role in the transport of harmful substances such as organochlorine antibiotics, polycyclic insecticides, aromatic hydrocarbons, and potentially toxic metals due to their diffuse nature, large specific surface area, and hydrophobicity. Therefore, all of these reasons may be the cause of changes in the concentration of calcium carbonate in soils treated with plastic granules compared to the control treatment.

Conductivity:

Figure (5) illustrate a significant decrease in the conductivity value, which recorded (1.326, 0.918), (1.428, 1.122), (1.02, 0.816), (0.918, 0.714) and (0.714, 0.816) milli-Siemens/cm when treating the soil with plastic granules at concentrations (50 and 100) gm/5 kg soil for each of the following types (PET, HDPE, LDPE, PVC and C), respectively. The lowest conductivity was when treating the soil with plastic granules of the PVC type at a concentration of (100) gm/5 kg soil and treatment with type C at a concentration of (50) gm/5 kg soil for each of them, and the conductivity reached (0.714) milli-Siemens/cm. While the highest degree of conductivity was recorded when treating the soil with HDPE plastic granules at a concentration of (50) gm/5 kg of soil, which recorded (1.428) % compared to the conductivity value recorded in the comparison treatment, which reached (1.836) milli-Siemens/cm**.**

The authors in [19] illustrate that contamination with microplastic particles changed many physical properties of soil such as a decrease in bulk density when treated with types (PEHD, PES, PET, PP, and PS) and soil water status when treated with types (PA, PES, and PS). On the other hand, it was observed that water evaporation increased with increasing polyethylene contamination [28]; plastic particles also cause impairment of soil structure, water dynamics, and microbial activities [24]. Microplastics can also absorb and accumulate hazardous chemicals on their surfaces, which increases their effects [21]. The degree and duration of the effects of plastic compounds on soil enzyme activities depend on the type, concentration, size, and shape of these compounds, in addition to the soil environment and other factors [29]. The presence of additives to plastic compounds is also a factor affecting many different soil properties [30]. Moreover, pesticides and other toxins present in the soil can accumulate on plastic debris and leach additives with different effects [31]. All of these reasons may be

a reason for affecting the degree of conductivity in soil samples contaminated with plastic granules.



	PET	HDPE	LDPE	PVC	C
control	1.836	1.836	1.836	1.836	1.836
50 gm	1.326	1.428	1.02	0.918	0.714
100 gm	0.918	1.122	0.816	0.714	0.816

Figure (5) Effect of treatment with different types of plastic and two concentrations of each type on the degree of conductivity (mS/cm) in the soil.

Conclusions

It was noted from the current research that treating the soil with plastic granules of the following types PET, HDPE, LDPE, PVC and C. At two concentrations of 50 and 100 gm/kg soil caused a significant decrease in the concentration of all nitrogen, phosphorus, calcium and electrical conductivity in the treated soils, while treatment with these granules caused a significant increase in the concentration of calcium carbonate in the soils compared to its concentration in soils not treated with these granules.

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References:

[1] Y. Jieru, A. Samuel, L. Xuelu, L. Xiaodan, S. Jing, and Z. Xiaoning, "Microplastics in soil ecosystem – A review of sources, fate, and ecological impact," *Plant Soil Environ*, vol. 68, no. 1, pp. 1–17, 2022.

[2] P. Europe, "Plastics–The Facts 2019: An Analysis of European Plastics Production, Demand and Waste Data," 2019, *Brussels, Belgium*.

[3] M. L. Trevor, "Chapter 1 - Introduction to Plastic Waste and Recycling," in *Plastic Waste and Recycling*, New York: Academic Press, 2020, pp. 3–12.

[4] Z. Steinmetz *et al.*, "Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?," *Science of the Total Environment*, vol. 550, p. 690−705, 2016.

[5] L. Nizzetto, M. Futter, and S. Langaas, "Are agricultural soils dumps for microplastics of urban origin?," *Environ Sci Technol*, vol. 50, p. 10777−10779, 2016.

[6] J. Peng, J. Wang, and L. Cai, "Current understanding of microplastics in the environment: Occurrence, fate, risks, and what we should do," *Integr Environ Assess Manag*, vol. 13, p. 476−482, 2017.

[7] A. A. Horton, A. Walton, D. J. Spurgeon, E. Lahive, and C. Svendsen, "Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities," *Science of the Total Environment*, vol. 586, pp. 127–141, 2017, doi: 10.1016/J.scitotenv.2017.01.190.

[8] I. A. Richard, *Diagnosis and Improvement of Saline and Alkali Soil*. in Handbook. U.S. Department of Agriculture, 1954.

[9] FAO, "Standard operating procedure for soil calcium carbonate equivalent: Titrimetric method," 2020, *Food and Agriculture Organization of the United Nations, Rome*.

[10] C. A. Black, *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. Madison, Wisconsin, USA: American Society of Agronomy, Inc, 1965.

[11] S. H. Antar, *Statistical analysis in scientific research and SAS program*. Mousl, Iraq: College of Agriculture and Forestry, University of Mosul, Dar Ibn Al-Atheer House for Printing and Publishing, 2010.

[12] S. Iqbal *et al.*, "Unraveling Consequences of Soil Micro- and Nano-Plastic Pollution on Soil-Plant System: Implications for Nitrogen (N) Cycling and Soil Microbial Activity," *Chemosphere*, vol. 260, p. 127578, 2020, doi: 10.1016/j.chemosphere.2020.127578.

[13] F. Meng, Y. Xiaomei, R. Michel, X. Minggang, and G. Violette, "Response of Common Bean (Phaseolus Vulgaris l.) Growth to Soil Contaminated with Microplastics," *Science of The Total Environment*, vol. 755, p. 142516, 2021, doi: 10.1016/j.scitotenv.2020.142516.

[14] D. He, Y. Luo, S. Lu, M. Liu, Y. Song, and L. Lei, "Microplastics in soils: Analytical methods, pollution characteristics and ecological risks," *TrAC Trends in Analytical Chemistry*, vol. 109, pp. 163–172, 2018, doi: 10.1016/j.trac.2018.10.006.

[15] M. C. Rillig, A. Lehmann, A. A. de Souza Machado, and G. Yang, "Microplastic effects on plants," *New Phytologist*, vol. 223, no. 3, pp. 1066–1070, 2019, doi: 10.1111/nph.15794.

[16] D. O'Connor *et al.*, "Microplastics Undergo Accelerated Vertical Migration in Sand Soil Due to Small Size and Wet-Dry Cycles," *Environmental Pollution*, vol. 249, pp. 527–534, 2019, doi: 10.1016/j.envpol.2019.03.092.

[17] R. Qi, D. L. Jones, Z. Li, Q. Liu, and C. Yan, "Behavior of Microplastics and Plastic Film Residues in the Soil Environment: A Critical Review," *Science of the Total Environment*, vol. 703, p. 134722, 2020, doi: 10.1016/j.scitotenv.2019.134722.

[18] A. McCauley, J. Clain, and J. Jeff, "Plant Nutrient Functions and Deficiency and Toxicity Symptoms," 2009, *Montana State University Extension*. [Online]. Available: www.mtvernon.wsu.edu/path_team/Plant-Nutrient-Functions-and-Deficiency-andToxicity-Symptoms-MSU-2013

[19] A. A. De Souza Machado *et al.*, "Microplastics can change soil properties and affect plant performance," *Environ Sci Technol*, vol. 53, no. 10, 2019, doi: 10.1021/acs.est.9b01339.

[20] F. Meng, X. Yang, M. Riksen, and V. Geissen, "Effect of Different Polymers of Microplastics on Soil Organic Carbon and Nitrogen—A Mesocosm Experiment," *Environ Res*, vol. 204, no. Pt A, p. 111938, 2022, doi: 10.1016/j.envres.2021.111938.

[21] F. Wang, Q. Wang, C. A. Adams, Y. Sun, and S. Zhang, "Effects of Microplastics on Soil Properties: Current Knowledge and Future Perspectives," *J Hazard Mater*, vol. 424, p. 127531, 2022, doi: 10.1016/j.jhazmat.2021.127531.

[22] Y. M. Lozano and M. C. Rillig, "Effects of microplastic fibers and drought on plant communities," *Environ Sci Technol*, vol. 54, pp. 6166–6173, 2020.

[23] Z. Jie *et al.*, "Microplastics as an emerging threat to plant and soil health in agroecosystems," *Science of the Total Environment*, vol. 787, p. 147444, 2021, doi: 10.1016/j.scitotenv.2021.147444.

[24] A. d. M. Anderson *et al.*, "Microplastics Can Change Soil Properties and Affect Plant Performance," *Environ Sci Technol*, vol. 53, pp. 6044–6052, 2019, doi: 10.1021/acs.est.9b01339.

[25] U. Udochukwu, E. I. Atuanya, and J. M. Abidemi, "Ecotoxicological Effects of Plastic-Enriched Composting Waste on Soil Biological Sentinels," *Nigerian Journal of Scientific Research*, vol. 16, no. 1, pp. 35–40, 2017.

[26] K. Harpreet and N. Anjana, "The Effects of Microplastics on Plant Growth and Soil Health in Agricultural Ecosystem," *IJFANS International Journal of Food and Nutritional Sciences*, 2022.

[27] A. H. Anik, S. Hossain, M. Alam, M. B. Sultan, M. T. Hasnine, and M. M. Rahman, "Microplastics pollution: A comprehensive review on the sources, fates, effects, and potential remediation," *Environ Nanotechnol Monit Manag*, vol. 16, p. 100530, 2021, doi: 10.1016/j.enmm.2021.100530.

[28] Y. Wan, C. Wu, Q. Xue, and X. Hui, "Effects of Plastic Contamination on Water Evaporation and Desiccation Cracking in Soil," *Science of the Total Environment*, vol. 654, pp. 576–582, 2019, doi: 10.1016/j.scitotenv.2018.11.123.

[29] H. Yu, Y. Zhang, and W. Tan, "The 'Neighbor Avoidance Effect' of Microplastics on Bacterial and Fungal Diversity and Communities in Different Soil Horizons," *Environmental Science & Ecotechnology*, vol. 8, p. 100121, 2021, doi: 10.1016/j.ese.2021.100121.

[30] N. Khalid, M. Aqeel, and A. Noman, "Microplastics could be a threat to plants in terrestrial systems directly or indirectly," *Environmental Pollution*, vol. 267, p. 115653, 2020, doi: 10.1016/j.envpol.2020.115653.

[31] L. Ramos, G. Berenstein, E. A. Hughes, A. Zalts, and J. M. Montserrat, "Polyethylene film incorporation into the horticultural soil of small peri-urban production units in Argentina," *Science of the Total Environment*, vol. 523, pp. 74–81, 2015.