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Soil Contamination by Plastics: Recycling of Plastic Waste and Soil Treatment of Landfills

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***Abstract*—The growing production and consumption of plastics has caused the accumulation of plastic waste in landfills, with adverse effects on the soil, ecosystems and human health. Soil contamination by plastics is a critical environmental challenge that requires urgent and effective measures. In this context, the 2030 Agenda seeks to address this problem through sustainable development objectives, one of which aims at waste management. To face the problem of soil contamination by plastics, solutions such as bioremediation and pyrolysis are explored in this study, with the aim of reducing soil plastic contamination and promoting a more sustainable approach towards waste management. This paper is expected to contribute to the discussion of alternatives for plastic pollution reduction and to raise awareness about this urgent challenge.**

***Keywords:* plastics contamination, soil contamination, pyrolysis, bioremediation.**

***Resumen*— La creciente producción y consumo de plásticos ha provocado la acumulación de residuos plásticos en los vertederos, con efectos adversos sobre el suelo, los ecosistemas y la salud humana. La contaminación del suelo por plásticos es un desafío ambiental crítico que requiere medidas urgentes y efectivas. En este contexto, la Agenda 2030 busca abordar esta problemática a través de objetivos de desarrollo sostenible, uno de los cuales apunta a la gestión de residuos. Para contrarrestar el problema de la contaminación del suelo por plásticos, en este estudio se exploran soluciones como la biorremediación y la pirólisis, con el objetivo de reducir la contaminación plástica del suelo y promover un enfoque más sostenible hacia la gestión de residuos. Se espera que este trabajo contribuya a la discusión sobre alternativas para reducir la contaminación por plásticos y crear conciencia sobre este desafío urgente.**

***Palabras clave*: contaminación por plásticos, contaminación del suelo, pirólisis, biorremediación.**

I. Introduction

As plastic production and consumption have rapidly increased, landfills are being filled with tons of plastic waste, which decomposes slowly. Plastic waste raises concern due to its detrimental impact on the soil and its consequences for ecosystems, biodiversity and human health. Because of this, soil contamination by plastics presents one of the most important environmental challenges of the present times and it is an issue that demands immediate attention and effective measures.

This situation and others were taken account at the time the 2030 Agenda for Sustainable Development was published. The United Nations' Sustainable Development Goals (SDG) Report consists of seventeen SDGs to achieve a fairer and more sustainable future for all people and the world [1]. These SDGs aims to promote global sustainability by addressing different challenges such as industry, innovation and infrastructure, and climate action. In relation with the land contamination by plastic, the SDG #11, which is called "Sustainable cities and communities", seeks to improve the quality of life in cities and human settlements. In particular the 11.6 target aims to promote sustainable management of waste [1].

However, the persistent nature of plastic pollution and the increase of plastic waste aggravates the problematic situation. Therefore, the issue of soil contamination by plastics requires an urgent discussion of proposals that address the reduction of plastic-polluted landfills, such as the recycling of plastics from landfills and their soil treatment, to achieve safe waste management. Among the different solutions to soil contamination by plastics in landfills, proposals such as bioremediation and pyrolysis are increasingly being used. The purpose of this paper is to discuss the impact of plastic waste in soil pollution and possible alternatives for the use and disposal of plastics.

Due to the need to study this topic, this paper will present two different methods of waste management from landfills. To achieve this goal, this work is organized as follows. In the first place, it will seek to identify the pollution properties from plastic materials, which are the focus of concern. Once identified, the methods proposed for the recycling of plastic materials, namely, bioremediation and pyrolysis, will be presented and described. Finally, the need for the recycling of waste in landfills will be considered. This paper is expected to contribute to the discussion of alternatives for plastic pollution reduction and to raise awareness about this urgent challenge.

II. Properties of Soil Contamination by Plastics

Plastic pollution is caused by human beings as a result of the introduction of polymeric materials from human industries into a natural environment from which they are alien. These contaminants generate a natural alteration when they are introduced into a different medium, which leads to the interruption, modification or deterioration of the natural state of said medium, which in turn, causes a disturbance in the balance of the Earth's systems [2].

The chemical reactions that are produced by polluting agents cause the transformation or transmutation of matter from their original form to a different one, and that process can be reversible or irreversible. Therefore, polluting agents affect the dynamics of matter and environments, affecting in turn, the natural characteristics of the living and non-living components of said environment. This effect, being cumulative, is what [2] has called *environmental stress.*

The wide impact of environmental pollutants and the transformation of matter is closely related to the presence and diverse applications of plastics, such as polyethylene, polyvinyl chloride (PVC), polyacrylamide, polyester, and polypropylene (PP), among others. These polymers are present in various products of human industries, including synthetic fibers, bags, packaging, paints and coatings, construction materials, medical devices, tires, and even cosmetic products. Therefore, it is imperative to understand their role in environmental stress and explore sustainable alternatives.

For the purposes of this research, plastic waste has been classified by the size of the waste in the natural environment. However, size classifications are not internationally standardized. Below are the most common types of plastic waste and their most notable effects.

A. *Contamination by macroplastics*

Macroplastic is defined by [3] as plastic items with a diameter greater or equal than 5 mm. These are larger plastic fragments, such as bags and packaging, which are easily visible to the naked eye. They can be transported by wind and water, ending up in the soil.

Macroplastics mainly affect the natural system insofar as they can modify the humidity and density of the earth. This makes it impossible for the sunlight and water to penetrate, which affects the natural system on the surface.

B. *Contamination by microplastics*

Microplastics (MP) are small pieces of plastic, with a diameter of less than 5 mm. In the environment, plastic waste is broken down by physical, chemical, and biological processes, such as ultraviolet radiation, erosion by wind or water, into smaller fragments, but it can also be generated directly during the manufacture of cosmetics for various purposes.

As described by [4], microplastics that enter the soil can be stored, transported, eroded, degraded, and leached into groundwater, threatening organisms and affecting human health. On the other hand, soil biota can influence the accumulation and fate of microplastics. A research project has shown that microplastics affect soil water availability, increase soil pH, decrease soil bulk density, and increase dissolved organic matter [5].

C. *Contamination by nanoplastics*

Nanoplastic particles (NP) are originated from the degradation of microplastics. Their size is less than 1 µm in diameter. The environmental impacts of nanoplastics will be different from those presented by microplastics, as their smaller size allows for penetration into tissues and accumulation in organs, which is a potentially significant issue given current concerns about the environmental behavior and ecotoxicity of manufactured nanomaterials, as [6] explains.

Nanoplastics have an effect on the food web of biotic systems due to their ability to be processed and assimilated by different living beings. In fact, worms are known to play a crucial role in generating these nanoplastics from microplastics. Subsequently, the nanoparticles are assimilated by soil bacteria, plants, fungi, and other living beings. However, there are technical and methodological difficulties for their study. Research has shown that nanoplastics contribute to the reduction in the growth rate and mortality of invertebrates, such as earthworms and microarthropods; have a deleterious effect on the survival and reproduction of nematodes; and interrupt the activity and microbial composition of the soil [5].

As it has been introduced in this section, the methods available to deal with the problem of soil contamination by plastics are oriented to different dispositions of the polluting agents in the soil. In the following sections, the available methods to soil contamination by plastics are described and their implementation viability is assessed according to the types of plastic waste presented in this section.

III. METHODS TO ADDRESS SOIL CONTAMINATION BY PLASTICS

To address soil contamination by plastics, it is crucial to find effective solutions to deal with this issue. In this context, two promising approaches have emerged as possible alternatives to deal with this problem: bioremediation and pyrolysis.

A. *Bioremediation*

The first alternative to address soil contamination analyzed in this paper is bioremediation. Bioremediation is the process in which microorganisms break down waste. It is a technique of biotechnology that focuses on detoxification and decontamination using microorganisms to biodegrade natural compounds that can be treated through the biodegradation of plants, algae, fungi, and bacteria. For bioremediation to be effective, optimal conditions are required in the culture medium, such as nutrients, enzymes, pressure, and temperature, which favor the growth of microorganisms. In the absence of any of these factors or in the presence of growth inhibitors, the bioremediation process will not be successful, as [7] states.

An important aspect of bioremediation is the ability of microorganisms to secrete metabolites, such as polyhydroxyalkanoate depolymerases, which are especially useful in breaking down microplastics and nanoplastics in the natural environment. Microbial degradation of plastics is usually influenced by several biotic and abiotic factors, such as enzymatic mechanisms, concentration of substrates and co-substrates, temperature, pH, oxidative stress, among others. Therefore, it is critical to recognize the key pathways taken by microbes to use plastic fragments as the sole carbon source for growth and development.

In this context, the role of various microbes and their enzymatic mechanisms involved in the biodegradation of micronanoplastics in wastewater streams, municipal sludge, municipal solid waste and composting for biological and toxicological impacts of micronanoplastics has been critically studied in [8]. In addition, there has been a thorough deployment of various remediation technologies such as enzymatic, advanced molecular, and biomembrane technologies to foster micronanoplastics bioremediation of various environmental compartments along with their advantages and disadvantages and prospects for future research.

The degradation of plastic polymers occurs when they are exposed to heteroatomic molecules, such as nitrogen or oxygen, and in the presence of a carbon double bond. These factors allow the initiation of biodegradation of plastic waste. To facilitate this process, extracellular enzymes are used, which act as chemical catalysts, reducing the activation energy and converting the substrate into simpler products, as shown in Fig. 1. Various enzymes are used at this stage, such as microbial oxidoreductases, microbial oxygenases, laccases, peroxidases, microbial lignin peroxidases, microbial hydrolases and manganese peroxidases, as well as microbial lipases [7]. As a result of this process, plastics break down into tiny droplets of materials, monomers, dimers, oligomers, molecules, water, methane, nitrogen, and carbon dioxide, as presented in [9].

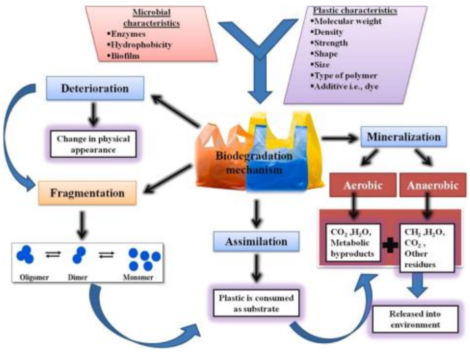

Fig. 1. Schematic diagram of the mechanism of microbial degradation of plastic waste [7].

Overall, bioremediation is a valuable technique that uses microorganisms to decompose and decontaminate waste in the environment. Its effectiveness depends on the optimal conditions in the culture medium and the ability of microorganisms to secrete useful metabolites in the collection of materials such as plastics. In addition, the action of enzymes is essential to facilitate the fragmentation and biodegradation of plastic polymers into their simplest components. With the proper use of these biotechnological tools, pollution problems can be more effectively addressed and it is possible to contribute to environmental protection.

B. Pyrolysis

Apart from bioremediation, this paper will analyze pyrolysis as another process to deal with soil contamination by plastics. Pyrolysis is a chemical and thermal process in which organic matter is broken down into its basic components. It is the process of converting gases and oils to recover crude petrochemical products and produce hydrocarbons, as well as producing crude petrochemicals and generating energy through plastic waste. Following [7], it can be said that the main categories of plastics used are thermosets and thermoplastics, with around 80% of the plastics used being thermoplastics. Thermoplastics have the ability to break down into different sizes of plastics. Thus they can originate microplastics, such as the plastic particles present in cosmetic products, macroplastics, such as water bottles and plastic bags, and nanoplastics, such as the nanoparticles used in coatings and electronic products. This principle is based on their easy molecular reforming capacity under thermal treatment and their susceptibility to change.

The products resulting from plastic pyrolysis depend on different factors such as the type of reactor, residence time, plastics, condensation arrangement, feed arrangement, and applied temperature. Although it can be costly, plastic pyrolysis is an efficient solution for waste management.

IV. ADVANTAGES AND DISADVANTAGES OF BIOREMEDIATION AND PYROLYSIS

In the constant pursuit of mitigating the adverse effects of plastic soil pollution, various techniques have been developed to address this challenge from different approaches. In this section, the advantages and disadvantages of the two techniques addressed in this paper, namely, bioremediation and pyrolysis, will be analyzed. Examining the advantages and disadvantages of these two approaches would allow a better understanding of their feasibility, environmental impact, and effectiveness in restoring contaminated soils. Subsequently, this paper will delve into the details of each technique and evaluate the way they contribute to reducing plastic soil pollution.

Bioremediation is an innovative and encouraging solution to treat soil contaminated by nano and microplastics. Recently, the biological decomposition of plastic has gained more prominence due to its heralding efficiency, profitability, environmental friendliness and sustainability [9]. Bioremediation techniques are often more economical than traditional methods such as incineration. As well as this, since bioremediation is based on natural attenuation, it is considered more acceptable than other technologies [10], since it is an option that uses natural biological activity to remove or render harmless contaminants.

Despite the advantages bioremediation offers, its ability to address various types of pollutants is limited, and its implementation can be a lengthy process. The complexity does not solely lie within the technique, but in the necessity to conduct precise site assessments and optimize conditions to achieve satisfactory outcomes. Although it presents itself as a promising alternative to conventional technologies, research in this field is still under development [10].

Plastic pyrolysis is also a promising solution for plastic waste management due to its various advantages. Firstly, it helps to reduce the amount of plastic in landfills by using plastic waste as the main product. Furthermore, this process enables the production of useful products such as fuel oil, coal and gas, which can have valuable applications and generate income. In addition, the pyrolysis of plastics contributes to the energy recovery of these waste materials. Its flexibility allows to adapt to a variety of plastic types, ensuring efficiency. Finally, this process generates low emissions of volatile organic compounds and dioxins, which is beneficial to the environment and human health, as [11] describes.

Despite its numerous advantages, plastic pyrolysis also has some disadvantages to consider, according to [11]. The process is technically complex, requiring specialized equipment and skilled operators. Additionally, its economic viability can be challenging due to high construction and equipment acquisition costs. Plastic pyrolysis also consumes a significant amount of energy, which can increase its carbon footprint. Lastly, the market for the resulting products may be limited due to competition from other energy sources and price fluctuations.

In summary, the search for solutions to counteract the negative effects of soil contamination by plastics has led to the development of various techniques, each one addressing the challenge from different angles. Both bioremediation and pyrolysis have unique advantages and disadvantages. Understanding their contrasting approaches and considering their pros and cons is essential for making informed decisions towards a more sustainable future in the fight against this problem.

V. CONCLUSION

In this study, the severe soil contamination caused by different types of plastics is addressed, highlighting their adverse impact on ecosystems and human health, resulting in concerning global consequences. Hence, it becomes crucial to tackle this issue and seek effective solutions. It is also noteworthy that the inclusion of this problem in the Sustainable Development Goals underscores its global significance.

Among the proposed strategies to address this issue, two main approaches have been explored: bioremediation and pyrolysis. The former relies on the use of microorganisms and living organisms to degrade and eliminate plastics from the soil, offering a more natural and sustainable option. On the other hand, pyrolysis is a chemical process that breaks down plastics through high temperatures, yielding valuable products like fuels or raw materials. The adoption of these strategies, along with robust education and awareness about proper plastic management, is essential to reduce pollution and safeguard our environment.

Both solutions come with advantages and challenges. Bioremediation can be a more environmentally friendly alternative, but it may require more time and resources to achieve effective results. In contrast, pyrolysis offers an efficient way to harness plastics as resources, but entails significant economic and technical costs.

Ultimately, the importance of addressing plastic soil pollution cannot be underestimated. The need for a multidisciplinary and global approach is evident, as this issue relates not only to the health of local ecosystems but also to global sustainability and conservation goals. To move forward, it is imperative to take concrete measures to reduce plastic usage, develop effective treatment technologies, and promote awareness and education at all levels of society. The challenge is substantial, but with collective action and informed decisions, it is possible to steer towards a cleaner and healthier future for the planet and its inhabitants.

In conclusion, further research is needed to analyze the economic performance, costs, economic benefits, and financial implications of both solutions. Another point for further investigation is the durability of these methods in terms of application effectiveness, maintenance, and long-term outcomes.

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The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering's Grand Challenges or the United Nations' Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students' developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar

Comentado [1]: preguntar a Laura donde poner su colaboración el paper