

Innovation in Technosols to promote urban agriculture in Barranquilla, Colombia  
 Innovación en Tecnosoles para impulsar la agricultura urbana en Barranquilla, Colombia  
 Inovação em Tecnosolos para promover a agricultura urbana em Barranquilla, Colômbia

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*Abstract*

Technosols are artificial soils developed from the reuse of solid waste, playing a fundamental role in improving soil quality and promoting more sustainable urban agriculture. Their implementation is essential to avoid waste, improve soil conditions, and encourage revegetation and biodiversity in urban areas. The purpose of this work is to demonstrate how domestic solid waste can be used to contribute to sustainable development goals and implement a circular economy. Instead of discarding this waste, it can be transformed into useful resources that improve soil quality by reusing organic and inorganic materials. This results in a high-quality Technosol, ideal for revegetating Barranquilla urban gardens. The development process of Technosols ensures that the final product has no toxic effects and has a suitable structure for plant growth. Furthermore, they provide the development of biomass through nutrients, C retention, and the fulfillment of the natural productive and environmental functions of the soil in its surroundings, as well as reduce the environmental or health risks derived from its management. Therefore, Technosols offers an innovative and sustainable solution for waste management and improving the urban environment in Barranquilla, Colombia.

*Resumen*

Los Tecnosoles son suelos artificiales desarrollados a partir de la reutilización de residuos sólidos, desempeñando un papel fundamental en la mejora de la calidad del suelo y promoviendo una agricultura urbana más sostenible. Su implementación es fundamental para evitar el desaprovechamiento de residuos, mejorar las condiciones del suelo y fomentar la revegetación y biodiversidad en áreas urbanas. El propósito de este trabajo es demostrar cómo se pueden aprovechar los residuos sólidos domésticos aportando a los objetivos de desarrollo sostenible e implementando economía circular. En lugar de desperdiciar estos residuos, se pueden transformar en recursos útiles que mejoran la calidad del suelo, reutilizando tanto materiales orgánicos como inorgánicos. Esto da como resultado un Tecnosol de alta calidad, ideal para la revegetación de jardines urbanos en Barranquilla. El proceso de desarrollo de los Tecnosoles, asegura que el producto final no tenga efectos tóxicos y posea una estructura adecuada para el crecimiento de plantas. Además, garantizar el desarrollo de biomasa mediante los nutrientes, la retención de C y el cumplimiento de las funciones naturales tanto productivas como ambientales del suelo en su entorno, y se reducen los riesgos ambientales o sanitarios derivados de su gestión. Por lo tanto, los Tecnosoles ofrecen una solución innovadora y sostenible para la gestión de residuos y la mejora del entorno urbano en Barranquilla, Colombia.

*Resumo*

Os Tecnosolos são solos artificiais desenvolvidos a partir do reaproveitamento de resíduos sólidos, desempenhando papel fundamental na melhoria da qualidade do solo e na promoção de uma agricultura urbana mais sustentável. A sua implementação é essencial para evitar desperdícios, melhorar as condições do solo e promover a revegetação e a biodiversidade nas áreas urbanas. O objetivo deste trabalho é demonstrar como os resíduos sólidos domésticos podem ser aproveitados, contribuindo para os objetivos de desenvolvimento sustentável e implementando uma economia circular. Em vez de desperdiçar estes resíduos, eles podem ser transformados em recursos úteis que melhoram a qualidade do solo, reutilizando materiais orgânicos e inorgânicos. Isto resulta num Tecnosolo de alta qualidade, ideal para a revegetação de jardins urbanos em Barranquilla. O processo de desenvolvimento da Tecnosols garante que o produto final não apresente efeitos tóxicos e possua estrutura adequada ao crescimento das plantas. Além disso, garantir o desenvolvimento da biomassa através de nutrientes, retenção de C e cumprimento das funções naturais, tanto produtivas como ambientais, do solo no seu ambiente, e que os riscos ambientais ou sanitários derivados da sua gestão sejam reduzidos. Portanto, a Tecnosolos oferece uma solução inovadora e sustentável para a gestão de resíduos e melhoria do ambiente urbano em Barranquilla, Colômbia.

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## 1. Introduction

Soil performs vital functions for living organisms, such as its human use for growing food, extracting raw materials, locating settlements, and other activities. Therefore, it is a finite resource vulnerable to various negative impacts of human activities. New technologies are being developed to mitigate its degradation and preserve its fundamental functions. The national circular economy strategy (ENEC) represents an initiative of the national government through the National Development Plan 2018-2022 that seeks to transform the country's productive systems through innovation and new business models. The ENEC requires schemes that allow rethinking, reusing, repairing, restoring, remanufacturing, reducing, repurposing, recycling, and recovering waste and materials (Ministry of Environment and Sustainable Development, 2023). The creation of Technosols contributes significantly to implementing a dynamic, inclusive, and sustainable economy in line with the commitment to sustainability that advocates the motto "produce by conserving and conserve by producing." Through the implementation of ENEC, the aim is to optimize the efficiency in the use of resources, thus promoting the circular economy and the management of Technosols for the benefit of the environment and society.

Technosols are composed of construction and demolition waste (CDW), such as concrete and broken ceramics, as [Chica & Beltrán \(2018\)](#) indicated. Industrial waste is also used, which is a by-product generated by industrial activities such as ash, sludge, glass, slag, plastic, fibers, cardboard, paper, and wood ([Román, 2017](#)). It is important to note that this waste may contain alkaline or acidic substances and heavy oils ([Barton, 2016](#)). Urban waste is generated mainly because of various domestic activities: food waste, pruning, and garden waste ([Weiler et al., 2020](#)), and rice husk ash ([Ruiz et al., 2020](#)). In addition, it is important to highlight that this waste contains high toxic concentrations such as Cd, As, Hg, and Pb; however, in considerable quantities, they favor vegetation growth ([Capasso et al., 2019](#)).

Technosols' properties, such as porosity and aeration, play a fundamental role in their functionality. Porosity can be defined as the volume not occupied by solid particles (empty spaces). Likewise, the porosity of the Technosol contributes to hydrological environmental services since water can be stored and transported through these spaces. Also, gases are housed, and biological activity is carried out in the soil ([González et al., 2012](#)). Regarding aeration, this property is influenced by the structure and texture of the soil, a clayey texture being a factor that can limit aeration and drainage. Most of the components found in Technosols provide minerals to the soil. Although construction and demolition waste contain few nutrients, it provides optimal porosity, aeration, and water retention ([Barredo et al., 2020](#)). Indicators are measurement tools that provide information on the soil's processes, characteristics, and properties, allowing it to verify its state and act through the requirements that the soil needs ([Estrada-Herrera et al., 2017](#)). Plants are considered visual indicators since their appearance and leaf color can reveal nutrient deficiencies ([Sadeghian, 2017](#)). On the other hand, organisms are also considered indicators of soil quality and functions. In addition, the activities carried out by these organisms depend on the properties of the soil, the type of vegetation cover, and the structure, among others ([Kooch et al., 2021](#)).

Many articles related to Technosols were carried out under mesocosm conditions; this means that through this technique, some parameters can be controlled to recreate scenarios on a smaller scale ([Alexander et al., 2016](#)). This is essential since Technosol can be applied to a degraded area without prior study and can cause serious damage if the soil requirements are unmet. Therefore, taking advantage of domestic solid waste in the city of Barranquilla is crucial to creating Technosols, thus ensuring the ability to improve soil conditions and promote environmental sustainability in the region.

Graphical abstract



## 2. Materials and methods

### 2.1. Study area and soil sample

Soil samples were taken from a garden in the Adelita de Char neighborhood, Barranquilla- Atlántico in the Riomar sector with coordinates 11°1'54"N 74°52'14" W (Figure 1). The protocol established in NTC 3656 was followed, taking the samples at a depth of 20 cm. The study area is characterized by a dry tropical climate, vegetation adapted to dryness, and an average temperature of 27 °C. The annual rainfall level reaches an average of 820 mm. The soil samples obtained were recorded by their location and depth.

Figure 1. Localization map study area.



### 2.2. Soil analysis before and after the application of Technosols

To perform the soil fertility analysis, which includes the evaluation of exchangeable acids and bases, cation exchange capacity, and pH, the samples were sent to the University of Passo Fundo's Agronomy laboratory in Brazil.

### 2.3. Technosols formulation

Technosols were formulated from organic and inorganic solid waste (Figure 2). The waste used was domestic waste generated daily in the neighboring houses of the Adelita de Char neighborhood in Barranquilla, Colombia. The formulation consisted of 9 kg of dry leaves, 6 kg of paper, 3 kg of cardboard, 10 kg of rubble, 10 kg of coffee powder, 7 kg of sawdust, peels (5 kg of plantain, 3 kg of orange, 4 kg of banana, 9 kg of potato, 7 kg of egg, 3 kg of cassava, 1 kg of torombolo, 2 kg of pineapple, 1 kg of watermelon, 4 kg of mango, 6 kg of carrot, 1 kg of garlic, 1 kg of onion, 1 kg of tomato, 1 kg of lemon, 1 kg of beet, 2 kg of cucumber, 1 kg of avocado). Production of Technosol began on May 2, 2023 (Figure 2).

Figure 2. Technosol production.



The waste was crushed into small fragments to accelerate its decomposition and reduce volume. Then, it was added to a plastic tank with a maximum capacity of 100 kg. The process included aeration by periodically mixing the waste every 5 days to ensure the presence of oxygen. The leachates generated during decomposition were collected and recirculated in the tank to preserve its nutrients and microorganisms. Finally, the materials were exposed to direct sunlight for drying (Figure 3).

Figure 3. Technosol aeration and drying process.



#### 2.4. Application of the Technosols in the Experimental Soil and Sunflower Seed

After sun drying, on July 30, 2023, 30 kg of the Technosol obtained was applied (Figure 4), which was spread in a thickness of 5 cm above the garden soil (Asensio et al., 2013). The area was 0.42 m wide and 1.8 m long, totaling 0.756 m<sup>2</sup>. 500 g of samples of the Technosol produced, and the experimental soil mixture was taken. Subsequently, sunflower seeds were sown.

Figure 4. Technosol application in the soil and sunflower seed sowing.



Sunflower seeds were purchased from a local nursery (Figure 4). They were shown on August 3, 2023, in the experimental soil (control) and the garden's mixture of experimental soil with Technosol.

### 3. Results and discussions

The addition of Technosols to the soil favored the availability of essential nutrients such as potassium (K), phosphorus (P), and magnesium (Mg), as shown in Table 1. These nutrients are fundamental in osmotic regulation, synthesizing ATP and chlorophyll, and promoting healthy plant growth (Ruiz et al., 2023). Comparative studies show that when Technosols were incorporated into the soil in previously degraded areas, there was a substantial increase in the levels of K, P, and Mg compared to soils not treated with Technosols (Ugolini et al., 2020; Lomaglio et al., 2017). This increase not only improved soil fertility but also resulted in more vigorous and productive plants, highlighting the effectiveness of Technosols in the recovery and optimization of soil conditions, which corroborates the results obtained in this work.

Table 1 Result of soil and Technosol analysis.

Sample	pH	P mg kg <sup>-1</sup>	Mg cmol+ kg <sup>-1</sup>	K cmol+ kg <sup>-1</sup>	Cu Mg kg <sup>-1</sup>	Zn Mg kg <sup>-1</sup>	Al+H cmol+ kg <sup>-1</sup>	CIC <sup>effective</sup> cmol+ kg <sup>-1</sup>
Experimental soil	8.0 (alkaline)	3.7 (low)	1.5 (sufficient)	0.1 (low)	5.2 (very high)	28.4 (very high)	0.9 (low)	2.5 (low)
Technosol	7.0 (neutral)	23.0 (very low)	3.8 (very high)	5.1 (very high)	0.3 (very high)	12.7 (very high)	1.1 (low)	27.9 (very high)
Soil without Technosol	6.9 (Neutral)	6.2 (low)	1.7 (sufficient)	0.2 (sufficient)	0.3 (very high)	4.9 (very high)	0.8 (low)	7.4 (low)
Soil with Technosol	6.5 (neutral)	27.0 (very low)	2.9 (high)	1.1 (very high)	0.2 (very high)	13.9 (very high)	1.0 (low)	19.7 (low)

Technosol produced from a combination of organic and inorganic solid waste has been formulated considering the optimal conditions for its development, which include adequate aeration, optimal levels of humidity and temperature, and an adequate balance between green and dry materials. In addition, waste containing appropriate nutrients has been added to improve soil quality. This process proved to be highly effective in improving soil fertility, as evidenced by the successful development of the sunflower (Figure 5), compared to the results obtained by sowing sunflower seeds in the experimental soil in Figure 4. In the experiment without Technosol, the seeds germinated after 5 days but there was no growth progress, and they died. The seeds in the soil with Technosol germinated after 3 days, continuing their growth, and flowered after 30 days.

Figure 5. Results of sunflower sowing in the control and experimental mixture.



Sunflowers were successfully grown in this Technosol due to several reasons. First, the combination of organic and inorganic residues provided the soil with essential nutrients for plant growth, which supported the healthy development of the Sunflowers' roots and foliage. Furthermore, the optimal conditions of aeration, humidity, and temperature promoted beneficial microbial activity in the soil, facilitating the decomposition of organic matter and the release of plant-available nutrients. Lastly, the proper balance between green and dry materials ensured a balanced degradation and gradual release of nutrients, which contributed to the maintenance of a soil environment favorable for the growth of Sunflowers.

#### 4. Conclusions

It is essential to encourage citizens to separate and use domestic solid waste properly and generate new technologies. As the increase in pollution and soil alteration is evident, it is necessary to implement treatments, technologies, and activities that guarantee adequate integral management of domestic solid waste in Barranquilla. As a result of this research, it has been demonstrated that Technosols are an economic resource capable of regenerating soils that adapt to the needs quickly to improve the quality of natural resources. This research allows the use of Technosols, a viable alternative to solve environmental problems, in pollution processes derived from waste generated by anthropogenic activities. They favor the reduction of waste management costs, minimizing energy and waste storage expenses. They increase the use of nutrients in this waste, incorporating it into the food chain. A plus of this environmental technology is that it does not produce new waste like other soil management techniques. Therefore, it is considered an integral process that meets the objective of a circular economy, where a new product is created from waste to improve soil conditions.

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#### Declaration of competing interests

The authors declare no conflicts of interest.

#### Author contributions

Conceptualization, methodology, data curation, writing and formal analysis, DPLS; writing-review and editing, and visualization, ALMR. All authors have read and agreed to the published version of the manuscript.

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