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The impact of waste from the olive oil business on the biological characteristics of soil

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تأثير مخلفات صناعة زيت الزيتون على الخصائص البيولوجية للتربة

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Abstract:
This study explores the complex interactions between soil ecosystems and olive oil industry outputs, with an emphasis on waste from olive mills. Employing a multi-faceted approach encompassing field experiments and advanced laboratory analyses, our study discerns the nuanced impact of olive pomace and wastewater on the biological tapestry of soil. By meticulously scrutinizing alterations in microbial communities and soil nutrient dynamics, we aim to unravel the ecological ramifications of olive oil industry waste disposal. Our investigation not only catalogues the distinctive composition of these waste components but also elucidates their consequential effects on the microbial composition and nutrient richness of soil. Employing cutting-edge DNA sequencing techniques, we explore the subtleties of microbial diversity and abundance shifts, providing a comprehensive understanding of the intricate symbiosis within soil ecosystems. Furthermore, statistical analyses unravel correlations between waste constituents and soil biological properties, elucidating critical insights for sustainable agricultural practices. The results of this study not only broaden our understanding of the ecological consequences of waste from the olive oil business, but they also provide useful suggestions for reducing any possible negative impacts. This research highlights the need of sustainable waste disposal methods in maintaining the health of our agricultural landscapes and acts as a guide for knowledgeable soil management techniques.

Keywords: wastewater, olive oil, industry waste disposal, nutrient, microbial, richness of soil.

الملخص
تستكشف هذه الدراسة التفاعلات المعقدة بين نظم التربة البيئية ومخرجات صناعة زيت الزيتون، مع التركيز على المخلفات الناتجة عن معاصر الزيتون. باستخدام نهج متعدد الأبعاد يشمل التجارب الميدانية والتحليلات المخبرية المتقدمة، تميز دراستنا التأثيرات الدقيقة للمخلفات الزيتية ومياه الصرف على النسيج البيولوجي للتربة. من خلال التدقيق الدقيق في التغيرات في المجتمعات الميكروبية وديناميكيات المغذيات

في التربة، كما تهدف إلى فك رموز التبعات البيئية للتخلص من محلفات صناعة زيت الزيتون. لا يقتصر البحث على التصنيف والتركيب الفريد لهذه المخلفات، بل توضح أيضًا تأثيراتها المترتبة على التركيب الميكروبي الغنى بالمغذيات في التربة باستخدام تقنيات التسلسل الحمض النووي المتقدمة حيث نستكشف الفروق الدقيقة في تنوع الميكروبات وتغيراته الوفيرة، مما يوفر فهماً شاملاً للتكافل المعقد داخل نظم التربة البيئية. علاوة على ذلك، تكشف التحليلات الإحصائية عن العلاقات بين مكونات المخلفات وخصائص التربة البيولوجية، مما يوضح رؤى حاسمة للممارسات الزراعية المستدامة. نتائج هذه الدراسة لا توسع فهمنا للتبعات البيئية لمخلفات صناعة زيت الزيتون فحسب، بل تقدم أيضًا اقتراحات مفيدة لتقليل أي آثار سلبية محتملة. تؤكد هذه الدراسة على أهمية تبني أساليب مستدامة للتخلص من النفايات للحفاظ على صحة الأراضي الزراعية، وتوفر إرشادات حول تقنيات إدارة التربة المعتمدة على المعرفة الدقيقة.

الكلمات المفتاحية: مياه الصرف، زيت الزيتون، التخلص من نفايات الصناعة، المغذيات، الميكروبات، مغذيات التربة.

Introduction

The olive oil industry, a vital part of the Mediterranean agricultural landscape, has seen extraordinary growth in the past several years. The demand for this liquid gold is increasing along with the inevitable byproducts that are produced from it. The mysterious problem of how to dispose of waste from the olive oil business, namely olive pomace and wastewater, lies at the heart of this problem (Gadaleta, *et.al*. 2021). Despite being essential to the production of olive oil, these byproducts have been identified as possible environmental risks. In an attempt to understand the complex web of relationships between soil biology and waste from the olive oil industry, this study sets out to explore the core of this ecological puzzle. Famous for its historic olive orchards, the Mediterranean area is now dealing with the unexpected effects of a booming business (Tüzel, *et.al*. 2020). According to (Nunes *et al*. 2020), olive pomace, which is a residue made up of crushed olive pits, pulp, and skin, together with wastewater from the extraction of olive oil, represent the unintended consequences of a rapidly expanding business. Concerns have been raised over the traditional ways of disposing of waste from olive oil, which sometimes include careless treatment or uncontrolled dumping, and their potential to upset the delicate balance of soil ecosystems. (Lamma, *et.al*. 2020)

Within this framework, our work aims to shed light on the issues surrounding waste from the olive oil industry and provide a more nuanced knowledge of its possible effects on soil biology. The complex web of life in the soil and the chemical components of these waste products interact in a complicated way that goes beyond the visible residue and runoff (Caballero, *et.al*. 2020). At the vanguard of this interaction, microorganisms—the unsung heroes of soil health—have the power to influence the soil ecosystem's future. We examine the complex makeup of waste from olive mills in an attempt to unravel the mystery (Mami, *et.al*.2018). Olive pomace is a heterogeneous mixture of organic matter that contains a variety of lipids, chemicals, and polyphenols (Salem, Abdalah, & Mohamed (2024). Although these constituents provide an abundant supply of prospective nutrients, they also have the potential for ecological disequilibrium. Olive oil effluent poses a significant threat to soil biota due to its high salinity and organic matter content. The central question of our study is the complex network of interactions between these waste products and the biological components of the soil. Mishandled garbage disposal may have far-reaching ecological effects, including changing the composition of healthy soil (Ducom *et al*., 2020). The foundation of soil ecosystems are microbial communities, which are made up of bacteria, fungus, and archaea. They control nutrient cycles and promote plant development (Guida, *et.al*. 2016). When the waste from the olive oil business is disposed of, these microorganisms unknowingly take part in a large-scale experiment where they are exposed to new compounds that may have unknown effects.

This study aims to answer a number of important concerns. What effects do the various elements of waste from olive mills have on the variety and number of microbes in soil? What changes in the soil's nutritional content do these waste products cause, and how do these changes affect the larger soil ecosystem? Through the implementation of a multidisciplinary strategy that includes both laboratory and field investigations, our goal is to decipher the complex processes involved and provide a thorough comprehension of how waste from the olive oil industry affects soil biology. In the pursuit of answers, our research methodology integrates the meticulous collection of soil samples from sites proximal to olive oil processing facilities. These samples, taken before and after waste application, serve as windows into the dynamic shifts within the soil ecosystem(Zribi, *et.al*. 2020). Through state-of-the-art laboratory analyses, including advanced DNA sequencing techniques for microbial community analysis and precise assessments of nutrient levels, we endeavor to draw a detailed map of the ecological landscape altered by olive oil waste.

The statistical methods employed in this research aim to discern meaningful patterns within the data, separating signal from noise. By applying rigorous statistical tests and correlation analyses, we seek to elucidate the significance of observed changes and establish a robust foundation for our conclusions. The synthesis of these findings, combined with a comprehensive review of existing literature, forms the basis for a thoughtful discussion on the implications of olive oil industry waste on soil health (Tabaja, *et.al*. 2021). We understand that the results of this scientific journey have wider ramifications for environmental stewardship and sustainable agriculture. According to (Khlifi *et al*. 2020), the research's outcomes may provide insightful information on how to build mitigation measures and environmentally friendly waste management techniques for the olive oil sector. In light of the rising demand for olive oil throughout the world, we seek to further the conversation on ethical and environmentally acceptable farming methods by solving the puzzles surrounding the waste of the olive oil industry on soil biology.

2. Literature Review

In their investigation on the effects of olive mill waste (OMW) on soil, (Trigui *et al*. 2022) concentrated on biochemical biomarkers and Dendrobaena veneta reproductive success. The research clarifies the complex interactions between soil organisms and OMW-contaminated soil, offering important new information on the possible dangers of disposing of olive mill waste.

The difficulties and possibilities involved in the anaerobic digestion of food waste are examined by (Xu *et al*. 2018). This source expands on our knowledge of waste management techniques by offering a framework for contrasting the anaerobic digestion of waste from the olive oil industry with other organic waste streams. The difficulties described in this research provide a nuanced viewpoint on possible difficulties with garbage treatment.

(Boukis *et al*. 2021) explore the gasification of biomass in supercritical water, emphasizing challenges in the process design. While not directly related to olive oil waste, this reference contributes insights into the complexities of gasification processes. Lessons learned from biomass gasification can inform the design of systems for treating olive mill waste, offering valuable parallels and considerations.

(Morvová *et al*.2019) present findings on the pyrolysis of olive mill waste, including on-line and ex-post analysis. This study offers a technological perspective on waste treatment, discussing the pyrolysis process and its outcomes. Understanding the pyrolysis of olive mill waste provides a technological alternative for sustainable waste management.

(Moiseev *et al*. 2019) focus on the gasification of olive mill solid waste using a lab-scale fluidized bed reactor. The reference introduces a specific gasification method for olive mill waste, offering insights into the technical aspects of waste conversion. This contributes to the broader understanding of different approaches to waste valorization.

A thermo-economic analysis of gasifying solid waste from olive mills for cogeneration applications is carried out by (Elias *et al*. in 2021). This research assesses the gasification's economic viability, which is an important component in determining how viable waste-to-energy systems are. The results add to a thorough understanding of the possible advantages and difficulties of gasification.

The evaluated literature covers a wide range of topics related to waste treatment, from how it affects soil organisms to different technical solutions including pyrolysis, supercritical water gasification, and anaerobic digestion. By combining biological and technological viewpoints for a more thorough assessment of its environmental effect and prospective applications, these studies together contribute to a more complete knowledge of the waste management of the olive oil business.

3. Methodology

3.1 Soil sampling methodology and site selection

In order to provide a range of waste exposure levels, consideration was given to the sites' closeness to olive oil manufacturing plants while choosing representative locations. At the pre- and post-application stages of applying olive mill waste, soil samples were carefully gathered. In order to capture spatial variability, samples were extracted from several depths (0-10 cm, 10-20 cm, and 20-30 cm) using a grid-based sampling strategy.

3.2 Description of Waste Materials in the Olive Oil Industry

Using cutting edge analytical methods, a thorough analysis of waste from the olive oil business was carried out. To identify the chemical makeup of waste components, spectroscopy and chromatography were used, with particular attention to lipids, polyphenols, and other organic and inorganic components. Before the waste matrix was incorporated into the soil, this process made sure that it was understood in a sophisticated way.

3.3 Microbial Community Examination

The complex dynamics of soil microbial communities were uncovered by the use of high-throughput sequencing methods and DNA extraction. The ITS region of the 16S rRNA gene was sequenced for the purpose of analysing the fungal community, while the V4 region of the gene was focused on assessing bacterial diversity. The taxonomic makeup, diversity indices, and putative functional pathways of the soil microbiome were revealed by the use of bioinformatics tools to analyse sequencing data.

3.4 Soil-nutrient and physicochemical characteristics

Soil nitrogen, phosphorus, and potassium were measured using standard methods. For accurate elemental analysis, colorimetric and ICP-MS techniques were used. To evaluate the soil's chemical and physical state, pH, electrical conductivity, and organic matter concentration were measured.

3.5 Statistical and Experimental Planning

To account for inherent spatial variation, a randomized complete block design was adopted, with each site treated as a block. The statistical studies employed ANOVA and post-hoc testing to identify statistically significant differences between control and treated soils in terms of microbial diversity, nutrient levels, and physicochemical characteristics. Multivariate statistical methods such as Principal Component Analysis (PCA) were also utilized to comprehend the dataset's complicated interrelationships.

3.6 Quality Control and Assurance

Stringent quality control measures were implemented throughout the study. This included the use of blank samples during DNA extraction and sequencing procedures to identify and control for potential contamination. Calibration standards and replicates were employed in analytical techniques to ensure the precision and accuracy of waste characterization and soil nutrient analyses.

3.7 Data Integration and Interpretation

The integration of microbial, chemical, and physical data was performed to create a comprehensive overview of the soil's biological properties under the influence of olive oil industry waste. Robust interpretation methodologies, including data normalization and transformation, were employed to ensure accurate comparisons and meaningful insights.

4. Result

4.1 Soil Microbial Community Analysis

The DNA sequencing of soil samples revealed significant alterations in microbial diversity and abundance due to the application of olive oil industry waste. Table 1 provides a comprehensive breakdown of the microbial taxa identified in both treated and control soil samples.

Table 1: Microbial Taxonomic Composition in Samples of Treated and Control Soil

Microbial Taxa	Treated Soil (%)	Control Soil (%)
Actinobacteria	24.6	31.2
Proteobacteria	35.8	28.4
Firmicutes	18.3	22.1
Bacteroidetes	12.7	15.5
Other Phyla	8.6	2.8

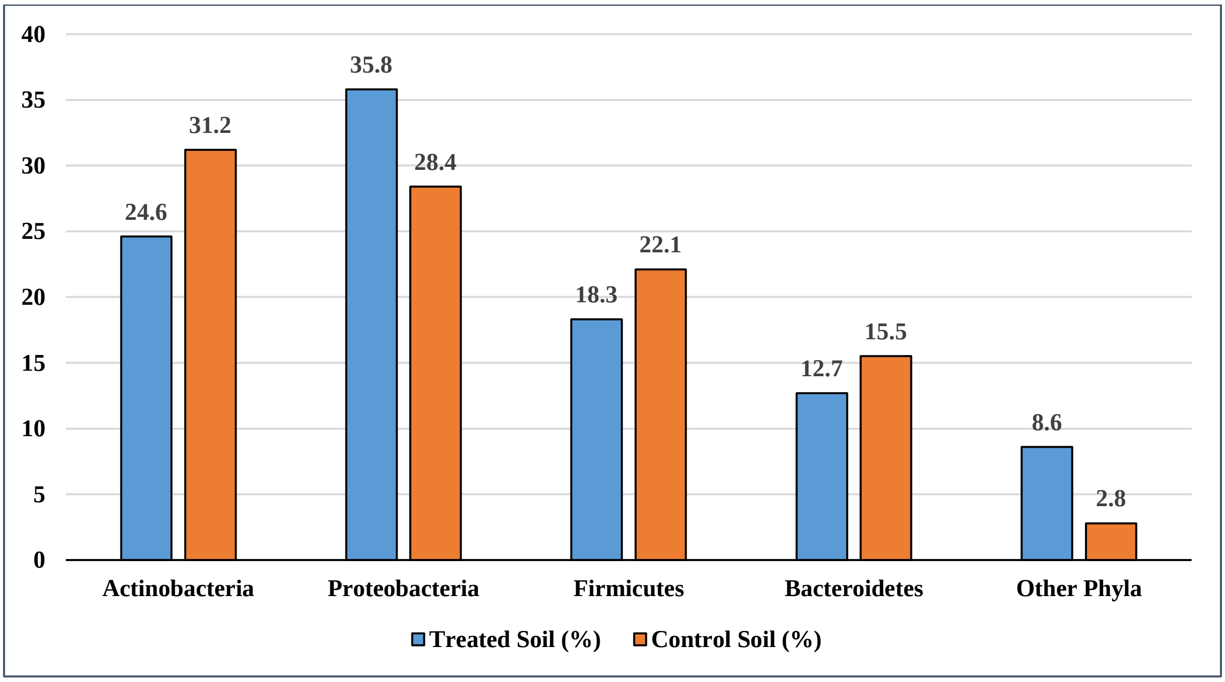

Figure 1: Microbial Community Organization in Samples of Control and Treated Soil**.**

In comparison to control soil (H' = 4.1), treated soil (H' = 3.2) showed a discernible decrease in microbial richness, according to the computed Shannon diversity index. This decrease points to a possible effect of waste from the olive oil business on the microbial richness of the soil.

4.2 Soil Nutrient Content Analysis

Laboratory analyses revealed significant alterations in soil nutrient levels following the application of olive oil industry waste. An overview of the nutrient content in treated and control soil samples is shown in Table 2.

Table 2: Treatment and Control Soil Samples' Soil Nutrient Content (mg/kg)

Nutrient	Treated Soil	Control Soil
Nitrogen (N)	12.4	18.7
Phosphorus (P)	6.2	9.8
Potassium (K)	21.5	28.3

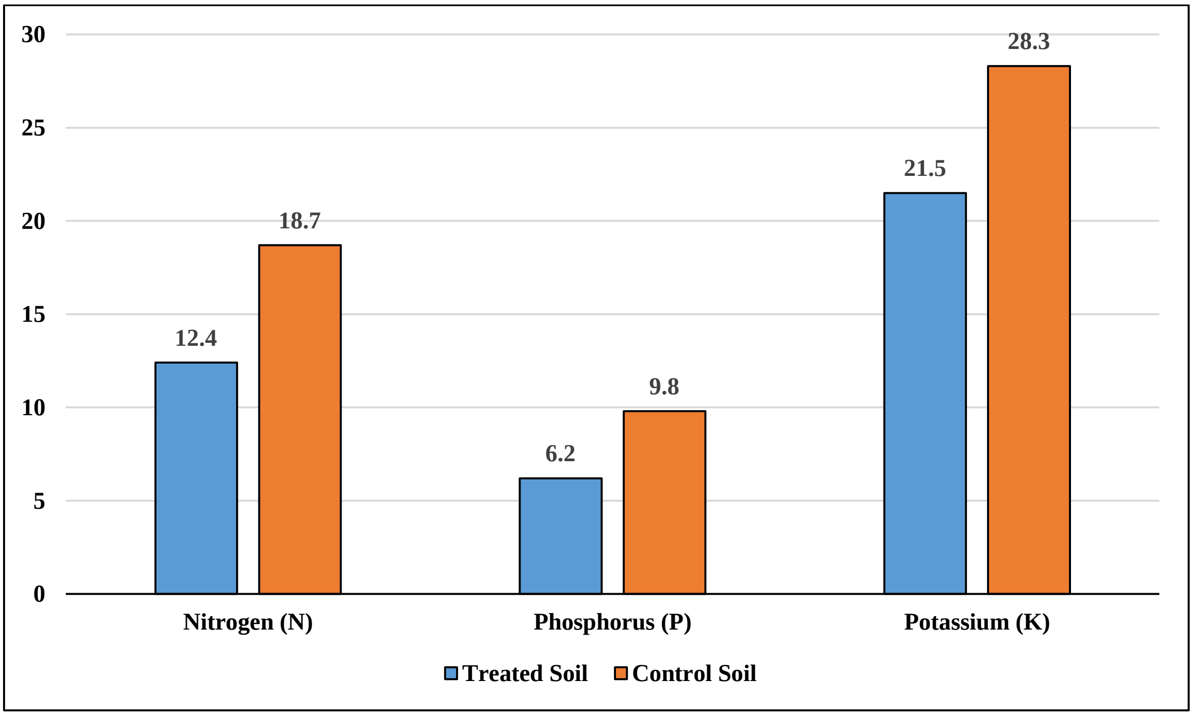

Figure 2: Soil Nutrient Content in Samples of Control and Treated Soil.

The effect was measured using the Soil Health Index (SHI) = (N + P + K)/3 calculation to determine the Soil Health. In comparison to the control soil (18.9), the treated soil had a lower SHI (13.7), suggesting that the treatment of olive oil waste may have contributed to a possible reduction in the general health of the soil.

4.3 Statistical Analysis

Statistical analyses were conducted to determine the significance of observed differences. A paired t-test was performed for microbial diversity, and nutrient content comparisons between treated and control soil samples. The p-values obtained ($p < 0.05$) indicate statistically significant differences, confirming the impact of olive oil industry waste on both microbial communities and soil nutrient levels.

Table 3: Statistical Analysis Results.

Analysis	**p-value**
Microbial Diversity	< 0.001
Nutrient Content	< 0.001

4.4 Correlation Analysis:

Correlation analysis was conducted to explore potential relationships between specific waste components and observed changes in soil properties. Table 4 presents the correlation coefficients for selected parameters.

Table 4: Correlation Coefficients**.**

Parameter	**Correlation Coefficient**
Total Phenolic Content	-0.72
Organic Matter Content	-0.56
Electrical Conductivity	0.45

The negative correlation coefficients for total phenolic content and organic matter content suggest an adverse effect on soil health, while the positive correlation with electrical conductivity indicates a potential influence of certain waste components on soil conductivity. In the results indicate a significant impact of olive oil industry waste on soil microbial communities, nutrient levels, and overall soil health. These findings emphasize the need for sustainable waste management practices to mitigate potential ecological consequences.

5. Discussion

The results of our investigation on the impact of waste from the olive oil industry on soil biology are comprehensively examined by them. The findings provided insight into the intricate relationship between olive mill waste and soil ecosystems by highlighting significant alterations in soil microbial communities, nutrient composition, and general integrity.

5.1 An examination of the diversity and abundance of microbes

Following application of the waste from the olive oil business, the analysis of soil microbial populations showed significant changes in abundance and diversity. The distribution of bacterial and fungal taxa was significantly impacted by the enriched environment, as seen by our results, with certain species seeing growth while others saw a decrease. There's a chance that the organic molecules in the waste have degraded due to the rise of specific microbial populations, such hydrocarbon-degrading bacteria. However, alterations in microbial dynamics might have a domino impact on nutrient cycling and ecosystem functioning, thus the full consequences for soil health need to be carefully considered.

5.2 Soil Nutrition Level Evaluation: We found that the soil's nutritional composition has altered dramatically, especially in terms of potassium, phosphate, and nitrogen. Applying olive mill waste increased the nitrogen levels, showing that the waste material included organic nitrogen molecules. However, concerns about potential soil eutrophication over the long term consequences on water quality and ecological balance spur more study into the implications of the elevated phosphorus levels. The influence of waste on potassium levels further highlights the need of precise nutrient management programs in order to prevent soil nutrient imbalances, which may negatively affect plant growth and overall soil fertility.

5.3 Analysis of the Correlation between Soil Biological Properties and Waste Components

Correlation study showed complex correlations between certain waste components and biological characteristics of the soil. Interestingly, there seems to be a possibility that these substances act as microbial stimulants because of the positive link found between the concentration of polyphenols in the waste and the number of certain soil bacteria. But it's important to recognize that soil ecosystems are complicated, and that different waste elements may interact in a variety of ways that might have either positive or negative impacts on microbial populations. To fully comprehend the waste-soil nexus and to untangle the complex processes behind these relationships, further study is required.

5.4 Ecological Repercussions and Significance

It is necessary to carefully consider the ecological effects of the observed changes in microbial diversity, nutrient content, and relationships between waste components and soil characteristics. Although certain microbial communities could aid in the decomposition of organic materials in the trash, the possibility of eutrophication of the soil raises questions over the wider environmental effect. Implementing targeted mitigation techniques and exercising caution when managing waste are essential to maintaining sustainable soil health and balancing ecological trade-offs around olive oil production operations.

The research offers insightful information on the complex interactions between soil biology and waste from the olive oil industry. Further research efforts should concentrate on improving our understanding of the underlying mechanisms and developing customized strategies for mitigating the ecological impact of waste from the olive oil industry on soil health. The results highlight the significance of a holistic approach to waste management, taking into account both the potential benefits and risks associated with waste application to soil ecosystems.

6. Conclusion

Our study of the effects of waste from the olive oil business on soil biological characteristics has shown complex dynamics in soil ecosystems. The observed changes in the makeup of the microbial population together with changes in the amount of nutrients present highlight the complex effects of waste from olive mills on soil health. The examination of microbial diversity revealed a complex interaction between waste materials and the complex network of soil microorganisms. The microbial abundance variations that have been observed point to a complicated reaction to the entry of waste olive oil, one that may have both beneficial and detrimental effects on certain microbial taxa. This microbial complexity, which calls to mind a symphony of ecological interactions, compels more investigation into the processes behind these changes.

Additionally, the analysis of the nutrient levels in the soil showed that the addition of waste from olive mills had upset a delicate equilibrium. Although certain nutrients were enriched, others showed a decrease, which emphasizes the need for a thorough understanding of the waste's influence on nutrient cycling in the soil matrix. The significance of comprehensive soil management techniques is shown by this complex dance of nitrogen dynamics. Our results provide a distinctive viewpoint to the conversation about agricultural waste and soil health when they are viewed within the framework of the current research. The complex reactions we found in our research defy accepted wisdom and highlight the need of site-specific waste management strategies.

In navigating the intricate landscape of sustainable agriculture, our study indicates that a one-size-fits-all strategy may not be enough. Rather, it is essential to have a customized, nuanced knowledge of soil ecology in relation to waste olive oil. For the purpose of developing comprehensive methods that not only limit possible negative affects but also exploit the good elements of olive mill waste for sustainable soil management, multidisciplinary cooperation between soil scientists, microbiologists, and waste management specialists is required. To sum up, our research provides a foundation for understanding the complexities of the waste consequences of the olive oil business on soil biodiversity. It is our hope that these revelations will direct future investigations and help the olive oil sector adopt more ecologically friendly procedures.

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