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Bioremediation of An Oil Drill Cutting with the Use of an Algal Extract as a Biofertilizer

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Abstract: ***Common practices in the oil industry generate a considerable amount of oil drill-cutting waste that requires treatment. This study aimed to analyze the biodegradation of hydrocarbons in oil drill cutting samples by using an algal extract from the Argentine Patagonian coast added as a biofertilizer, and compare the results with the use of synthetic fertilizers. The total petroleum hydrocarbon (TPH) content and bacterial count of the samples were determined after two months of treatment. Results showed that the presence of the algal extract improves natural biodegradation, but that the use of chemical fertilizers achieves better results.***

Keywords: Algal extract, Oil drill cutting, Hydrocarbons, Bioremediation

1. Introduction

As a result of oil extraction, oil waste is generated (Chaillan et al., 2006). The oil drill cuttings generated during drilling works are composed of soil, rock fragments, and pulverized material (Kogbara et al., 2016) and include drilling muds that are used to lubricate and cool the bit (Mauger et al., 2014). Drill cuttings are generally contaminated with hydrocarbons and high concentrations of metals such as As, Cr, Cu, Pb, Ni, and Zn (Kogbara et al., 2016; Balgobin et al., 2012; Johnson and Graney, 2015). These contaminants must be properly disposed of because they have mutagenic, carcinogenic, and teratogenic effects (Li et al., 2021).

A method that has been proposed for the treatment and removal of these hydrocarbons is bioremediation (Chaillan et al., 2006). *In situ* bioremediation, which involves the use of indigenous microorganisms, is the method most used to remove crude oil from contaminated sites (Ojewumi et al., 2017). The success of the treatment depends on factors such as the temperature, pH, moisture, nutrients (Margesin and Schinner, 2001), availability of electron acceptors, and type of soil (Antízar-Ladislao et al., 2006). Soil bioremediation is a process that uses the metabolic versatility of microorganisms to remove hazardous contaminants, converting organic contaminants into harmless compounds, such as carbon dioxide and water. This technology is viable if microorganisms can acquire new metabolic pathways and synthesize appropriate enzymes to degrade contaminants in a reasonable period (Alshehrei, 2017).The biodegradation of contaminants can be accelerated by the use of aeration and organic and inorganic fertilizers, which generate biostimulation by providing nutrients that enhance the indigenous bacterial population (Lladó et al., 2012).

The effectiveness of this fertilization depends on the initial carbon and nutrient needs of the indigenous microbial population, making it difficult to generalize and know the appropriate values to improve biodegradation (Nervo et al., 2017; Ite and Ibok, 2019). The necessary amount of nutrients such as nitrogen and phosphorus varies depending on the type of microorganisms, the carbon source, and the habitat (Ouriache et al., 2020).

Biofertilizers are compounds that contain living cells of different types of microorganisms that, applied to seeds, the surface of plants, or the soil, promote growth and improve their properties by converting nutritionally important elements (nitrogen, phosphorus) from forms not available to forms available through biological processes such as nitrogen fixation and solubilization (Rokhzadi et al., 2008). Biofertilizers, which are also known as microbial inoculants, improve soil structure and biodiversity (Kawalekar, 2013). In addition, they are organic, ecological, profitable, non-toxic, and easy to apply preparations, making them an effective alternative to chemical fertilizers (Khan et al. al., 2018; Youssef and Eissa, 2014).

Algae are organisms commonly used as fertilizers or compost (Naylor, 1978). This is due to their high content of nitrogen, phosphorus, and potassium (Suleiman et al., 2020), as well as other compounds that act as soil conditioners and stimulate, among other things, plant growth (Chapman, 2013; Duarte et al., 2018; Ammar et al., 2022). The most used algal species are brown algae, such as *Macrocystis* sp. and *Ascophyllum* sp. (Salamanca, 2005). Among all the species of brown algae, only a few have been the subject of studies on their possible applications in soils (Ammar et al., 2022; Chatterjee et al., 2017). *Ascophyllum nodosum* is one of the most researched species in this aspect, and has been used in the production of biofertilizers and soil amendments due to its content of nutrients and bioactive compounds, and its ability to improve the physical and biological properties of the soil (Shukla et al., 2019; Yurkevich et al., 2022). Another species of interest in terms of its possible applications in agriculture and soil fertility is *Fucus vesiculosus* (Yurkevich et al., 2022). *Undaria pinnatifida* is an edible brown alga native to northeast Asia, which has characteristics of an invasive species (Gil et al., 2015). In the Argentine Patagonian coast, the first specimens of this alga were found in 1992. This invasive species has been used as biocarbon to remediate

water bodies contaminated with antibiotics such as tetracycline (Annamalai and Shin., 2023).

The application of algae in the treatment of petrochemical effluents has recently gained popularity due to the fact that they can synthesize lipids and other high-value biomolecules (Yadav et al., 2021). Microalgae have been used in the treatment of water contaminated with recalcitrant organic compounds from accidental spills or domestic, agricultural, or industrial effluents (Almaguer et al.,2021; Rempel et al.,2021). These organisms have also been used in consortia with bacteria to remove heavy metals, reduce biochemical and chemical oxygen demands, or degrade organic compounds (Salcedo-Martínez et al., 2019). In a study carried out by Ashwaniy et al. (2020), the microalga *Scenedesmus abundans* was used in a bacterial co-culture to reduce organic compounds in oil refinery wastewater. In another study, Huo et al. (2019) used the filamentous microalga *Tribonema* sp. to remediate petrochemical wastewater effluents. These authors found that *Tribonema* sp., grown in anaerobic effluent, showed the greatest growth and was most effective in removing contaminants from wastewater. The total nitrogen removal rates, chemical oxygen demand, and biomass concentrations found by Huo et al. (2019) were 4.4 g/L, 98.4%, and 96.8%, respectively. Madadi et al. (2016) also studied the effectiveness of the microalga *Chlorella vulgaris* in the bioremediation of petrochemical effluents.

The use of algae as biofertilizers is a possible alternative for the biodegradation of hydrocarbons from soils.

Thus, the aim of this study was to evaluate the use of an extract of an algal mixture as a biofertilizer in the bioremediation of oil drill cutting waste and to compare these results with the use of synthetic fertilizers.

2. Material and Methods

Experimental samples
Soil samples were collected from a cutting repository in the Vaca Muerta oil field, Neuquén, Argentina. The samples were taken at depths between 10 and 30 cm. The samples were characterized according to the standard soil analysis method (Table 1). The algal extract was obtained from Biotec S.A. (Chubut, Argentina).

Biodegradation assays
Biodegradation was evaluated in six closed bottles with oxygen electrodes (OxiTop). The aerobic biodegradation reactions of organic compounds consume a certain amount of oxygen and produce carbon dioxide, which is absorbed by the solid granules of sodium hydroxide. The OxiTop Respirometric method was used following international standard methods (ISO 1990) for 60 days at 28°C.

Two of the six closed bottles were used as controls: one of them contained the initial soil without any aggregate and the other contained soil with moisture.Regarding the remaining four bottles, one contained soil added with pure algal extract, other two contained soil added with dilutions of the same extract at 1:10 and 1:100, and the other contained soil added with synthetic fertilizers at 100:10:1.

Plate counts
The number of culturable microorganisms was determined by the standard plate count method. Soil suspensions were prepared by vigorously shaking 10 g of soil in 90 mL 0.9% NaCl for 30 min. Then, 100 µL of each dilution level was plated on R2A agar (Reasoner and Geldreich, 1985). Oil-resistant populations were quantified on mineral base medium (MBM) where crude oil (1% in the medium) was added. The results are expressed as colony forming units (CFU).g-1 and one ratios were used: hydrocarbon-degrading bacteria (HDB) versus total bacteria (R2A).

Determination of hydrocarbons via gas chromatography analysis
Each sample (2 g) was dissolved in 5 mL of pentane, phase-separated, and percolated through 2 g of silica gel. Then, 1 mL of the eluate was carefully evaporated until dry to determine the fuel oil content of the sample. The fractions were analyzed and quantified by gas chromatography using a Varian 3800 gas chromatograph, equipped with a split/splitless injector, a flame ionization detector, and a capillary column VF-5ms (30 m, 0.25 mm, 0.25 µm). The injector and detector temperatures were maintained at 200°C and 340°C respectively. The sample (1 µL) was injected in split mode and the column temperature was raised from 45 to 100°C at a rate of 5°C/min and a second ramp from 100 to 275°C at a rate of 8°C/min. The final temperature, of 275°C, was maintained for 5 minutes.

Analysis of chromatograms
The chromatograms obtained were analyzed for the total petroleum hydrocarbon (TPH) content. The TPH content was divided into four fractions, taking into account the number of carbons: between C10 and C12, between C12 and C16, between C16 and C22, and between C22 and C34.

Statistical analysis
Results were analyzed using ANOVA with the BIOM program (Applied Biostatistics Inc.3 Heritage, Setauket, NY 117ll, USA). The results are shown in a graphical form and the tables include the average value of triplicates with their standard deviations.

3. Results

The initial soil sample had low moisture and neutral pH (Table 1). The physicochemical characterization of the algal extract indicated that it has high electrical conductivity (EC) and a high concentration of nitrates, phosphates, and chlorides (Table 1).

Table 1: Physico-chemical analysis/properties of the initial soil and the algal extract evaluated.

	Initial soil	Algal extract
Moisture	4.8	--
pH	7.06	5.69
EC	8300	27600
Chloride	3298,94	3972.4
Sulfate	2250	674.85
Carbonate	< 1	< 1
Bicarbonate	-	68.6
Calcium	3298.94	20
Magnesium	291.10	600
Nitrite	0.31	5.17

Nitrate	42.6	132.88
Ammonium	1.44	4.26
Phosphate	10.16	969.1
Sodium	867.67	8069.10

The pH values of the samples ranged from 6.32 to 7.93 (Table 2). After bioremediation with inorganic fertilizer for 60 days, the soil exhibited a slight increase in alkalinity. This could be attributed to microbial activity and the buffering effect of certain cationic substances (such as potassium, calcium, magnesium, etc.) (Myazin et al., 2021).

Table 2: Physico-chemical analysis/properties of the soil of the different assays performed.

	PAE	AE 1/10	AE 1/100	SF 100:10:1	SS	SH
Moisture	12.93	11.9	13.2	11.39	4.8	13.01
pH	7.93	6.55	6.32	7.67	6.42	6.86
EC	9090	8590	8490	11500	8250	8100

PAE: pure algal extract; AE: algal extract; SF: synthetic fertilizer; SS: initial soil without any aggregate ; SH initial soil with moisture; EC: electrical conductivity

After the 60 days of treatment, the TPH content of the samples treated with the biofertilizer and the synthetic fertilizer decreased between 40 and 50%, whereas that of the control samples decreased between 29 and 30% (Table 3). A decrease in the degradation of C8-C16 carbon chains was observed.

Table 3: Total petroleum hydrocarbon (TPH) content (ppm) .

.	**Initial soil**	**PAE**	**AE 1/10**	**AE 1/100**	**SF 100:10:1**	**SS**	**SH**
TPH	63892.38	36538.89	38241.28	37631.69	31894.66	45331.29	43774.76
nC6-nC8	676.52	639.40	639.11	656.72	124.64	640.00	624.92
nC8-nC10	866.64	24.39	21.79	20.64	20.70	0.00	23.48
nC10-nC12	2214.01	69.29	120.00	134.80	8.57	5.56	143.20
nC12-nC16	13869.17	711.31	662.70	659.35	635.34	934.96	13260.20
nC16-nC21	26937.45	18909.41	20143.44	19509.35	17093.38	26115.38	18391.60
nC21-nC35	17973.56	16185.09	16654.24	16650.83	14012.03	17635.39	11331.36
Hydrocarbon	**ppm**	**ppm**	**Ppm**	**Ppm**	**ppm**	**ppm**	**ppm**
C6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C7	70.36	58.64	49.80	57.65	69.54	66.37	51.32
C8	100.69	46.58	92.68	62.85	55.10	23.25	0.00
C9	40.90	18.10	21.79	20.64	20.70	0.00	0.00
C10	87.22	0.00	0.00	0.00	0.00	0.00	0.00
C11	298.70	0.00	0.00	0.00	0.00	0.00	0.00
C12	553.40	8.50	11.41	6.05	8.57	5.56	9.26
Naphthalene	310.95	0.00	0.00	0.00	0.00	0.00	0.00
C13	795.19	23.03	18.01	9.73	8.57	18.42	13.28
2-Methyl naphthalene	62.01	0.00	0.00	0.00	0.00	0.00	0.00
1- Methyl naphthalene	48.08	0.00	0.00	0.00	0.00	0.00	0.00
C14	994.60	61.56	18.01	13.54	26.17	20.77	13.22
C15	1244.98	65.78	73.13	69.62	65.98	104.96	85.80
Acenaphthylene	91.24	7.33	77.69	74.55	7.32	5.50	81.38
Acenaphthylene	347.08	34.77	44.61	40.30	0.00	0.00	0.00
C16	1435.75	305.80	312.92	322.45	319.61	452.62	375.42
C17	130.26	801.94	757.50	800.03	908.62	1085.15	839.47
Pristane	623.75	390.59	394.71	400.80	405.43	515.19	350.60
C18	2884.75	1759.05	1618.07	1665.61	1410.96	2229.67	1827.80
Phytane	336.48	298.41	297.35	354.79	307.62	357.69	231.32
C19	611.87	1489.90	1606.15	1346.32	1451.31	2473.95	1743.07
Phenanthrene	1118.26	523.90	808.07	770.12	825.29	945.29	774.32
C20	0.00	1461.09	1376.23	1286.49	1131.36	1844.80	1449.02
C21	795.55	1207.25	1316.75	1164.75	192.01	1682.95	1281.51
C22	694.52	1067.58	1066.96	914.88	1157.24	1321.52	978.27
Fluoranthene	516.36	403.50	423.04	328.56	420.27	479.68	330.00
C23	212.32	961.20	984.73	812.98	1016.39	1188.42	836.51
Pyrene	456.15	398.50	82.17	322.71	411.23	0.00	605.67
C24	1028.36	779.17	838.84	648.18	848.64	975.78	637.26
C25	885.08	696.20	753.14	587.70	734.21	835.02	529.86
C26	85.12	506.32	195.05	433.35	557.96	612.66	344.90
C27	259.02	117.03	170.43	96.50	109.75	121.81	243.53
Benzo(a)anthracene	274.57	273.89	37.95	235.08	301.62	0.00	16.44
Chrysene	0.00	18.10	192.48	17.29	26.43	0.00	8.52
C28	256.60	141.16	186.46	121.48	166.23	187.81	137.40
C29	321.21	85.24	82.75	75.86	100.65	103.51	85.94
C30	270.91	0.00	52.43	43.91	63.54	63.53	56.96
C31	243.89	0.00	27.69	33.92	36.65	41.43	33.07

benzo(b)fluoranthene	122.94	0.00	0.00	0.00	0.00	0.00	0.00
C31	0.00	0.00	18.27	19.98	30.06	24.88	22.41
Benzo(k)fluor	0.00	5.25	16.34	9.47	12.00	0.00	0.00
C33	0.00	0.00	0.00	0.00	0.00	9.12	0.00
C34	0.00	0.00	0.00	0.00	8.90	0.00	0.00
C35	0.00	0.00	0.00	12.03	0.00	0.00	0.00
Benzo(a)pyrene	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C17/pristane	2.181	2.053	1.919	1.996	2.241	2.106	2.394
C18/phytane	8.573	5.895	5.442	4.695	4.587	6.234	7.902

PAE: pure algal extract; AE: algal extract; SF: synthetic fertilizer; SS: initial soil without any aggregate ; SH initial soil with moisture

After the 60 days of treatment, the TPH content in the samples treated with the chemical fertilizer (SF) decreased by 50.08%, whereas that in samples treated with the algal extract (AE) decreased by 40–42%. The bioremediation process with algae extract achieved a notable reduction of approximately 40% in the TPH content, while the control sample (SS, SH) only showed a decrease of 29-31% (Table 3). These results demonstrate the effective performance of the chemical fertilizer applied in bioremediation. The substantial decrease in the TPH content in the soil after bioremediation is consistent with findings reported in the literature for soil samples from another basin (Cambarieri et al., 2021; Rondon-Afanador et al., 2023).

Gas chromatography analysis detected petroleum hydrocarbons in the soil (Table 3). The gas chromatograms showed peaks representing TPHs with atom ranges from C6 to C35, both before and after bioremediation. After bioremediation, the size of the peaks in the chromatograms showed a significant decrease (Table 3).

Initially, the soil sample presented significant amounts of hydrocarbons with C17/pristane and C18/phytane indexes. A decrease in these indexes was observed in both the samples and the controls, being more pronounced in the systems that contained the algal extract as a biofertilizer (Table 3).

The C17/pristane and C18/phytane indexes allow determining whether the reduction in hydrocarbons in the systems is attributable to a biodegradation process (Minai-Tehrani et al., 2015). These indexes compare a highly biodegradable hydrocarbon, such as the n-alkane heptadecane (C17) or octadecane (C18), with the isoprenoids pristane or phytane, which are very poorly biodegradable (Acuña et al., 2020). The decrease in these indexes indicates that C17 or C18 hydrocarbons decrease to a greater extent than pristane or phytane, suggesting that this reduction could be associated with a biodegradation process carried out by microorganisms.

Figure 1 shows that carbon dioxide production was greater in the system with synthetic fertilizers and in that containing the pure algal extract. This shows that the microbial biomass is greater in these systems, which reached the highest rates of hydrocarbon biodegradation. The difference observed between the system that contained the pure extract and the systems that had the diluted extract could be attributed to the fact that the pure extract provides microorganisms typical of this organic fertilizer.

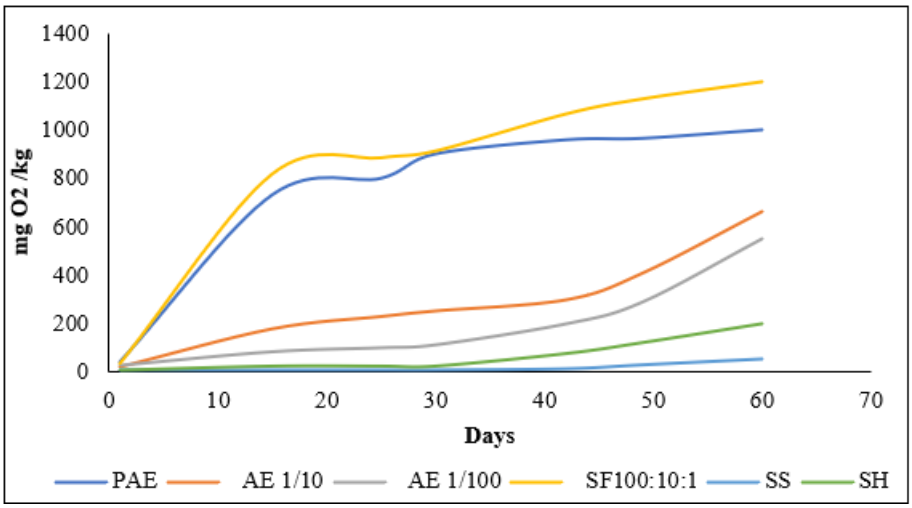

Figure 1: Response of soil cumulative mineralized CO_2, fertilizer addition, and different concentrations of algal extracts, after incubation for 60 days. PAE: pure algal extract; AE: algal extract; SF: synthetic fertilizer; SS: soil without any aggregate; SH: initial soil with moisture

The presence of total bacteria and HDB in the soil before bioremediation was around 10^{5-6} CFU/g^{-1}, whereas that after bioremediation was 10^{6-7} CFU/g^{-1}. In the control sample without added moisture, the presence of these microorganisms was 10^{5} CFU/g^{-1} (Table 4).

Table 4: Bacterial biomass count (CFU/g^{-1}).

	HDB		R2A			
	30 days	60 days	30 days	60 days	HDB/R2A 30 days	HDB/R2A 60 days
PAE	8.20×10^5	1.29×10^6	1.53×10^7	2.56×10^7	0.054	0.05
AE 1:10	1.01×10^7	1.60×10^7	1.21×10^7	2.49×10^7	0.835	0.643
AE 1:100	1.02×10^7	2.18×10^7	1.94×10^7	8.50×10^7	0.526	0.256
SF 100:10:1	1.80×10^5	1.93×10^5	5.50×10^5	6.90×10^5	0.327	0.28
SS	2.40×10^5	2.36×10^5	7.20×10^5	7.30×10^5	0.333	0.323
SH	2.18×10^7	5.60×10^7	2.50×10^7	1.13×10^8	0.872	0.496
Initial	7.40×10^5		1.0×10^6		0.685	

HDB: hydrocarbon-degrading bacteria; R2A: total bacteria

The number of microorganisms can vary depending on the bioremediation conditions and the contact time with the contaminant. In this case, the soil used for this study was from old contamination, so the microbial community found in it is composed of a bacterial pool with the physiological capacity to tolerate the presence of the contaminant and use it as a substrate.

The high number of active aerobic microorganisms in soil samples could be beneficial in the ability to utilize hydrocarbons. Similarly, a significant number of HDB were present in the soil samples before and after bioremediation, with a slightly lower count in the control sample.

The HDB/R2A ratio is important to know the bioremediation potential, because it indicates the capacity for contaminant decomposition (Gojgic-Cvijovic et al., 2012). The dynamics of the population changed with the degradation of hydrocarbons, with the HDB population decreasing when the fractions that degraded more rapidly decreased.

4. Discussion

In this study, the TPH content was effectively reduced in the four systems tested and their controls. Biostimulation of the indigenous bacterial community by providing nutrients and moisture for the degradation of hydrocarbons is one of the most widely used technologies for the elimination of these contaminants (Al-Hawash et al., 2018; Pucci et al., 2011).

The control system (SS) exhibited a notable degradation rate due to the natural attenuation of the soil. The sample came from an old contamination, which implies that the bacterial pool present is physiologically adapted to the contaminant. The system takes advantage of the potential of the pre-existing bacterial community, which has adapted to the environment, which, in the southern areas of Argentina usually presents extreme conditions (Lewin et al., 2013; Pucci et al., 2013).

The addition of moisture to the soil of the control system (SH) improved soil bioattenuation. Literature data indicate that moisture has a strong effect on biochemical processes in contaminated soils between 10 and 15% or 50% water holding capacity (Pucci et al., 2015; Myazin et al., 2021). The moisture content in the microcosm during bioremediation was within the limits that are optimal for this technique (Acuña and Pucci, 2022; Gupta et al., 2021).

The use of synthetic fertilizers in the form of inorganic salts favors the bioavailability of phosphates and nitrates for use. However, there are concerns about the adverse environmental effects derived from their application, such as the emission of greenhouse gases and the contamination of terrestrial and aquatic ecosystems (Dincă et al., 2022).

On the other hand, the use of biofertilizers represents a viable alternative to mitigate the adverse effects of environmental pollution associated with the use of synthetic fertilizers. Organic fertilizers gradually release primary nutrients and micronutrients into the soil, contributing to maintaining a nutritional balance (Dincă et al., 2022) and improving soil structure, thereby promoting healthy plant growth and soil microbial biomass (Lewu et al., 2020). Furthermore, the application of biofertilizers can increase the absorption of nutrients and transform initially unavailable elements into easily assimilated forms through biological processes (Vessey, 2003).

The difference between the immediate availability of nutrients from synthetic fertilizers and the gradual release of nutrients in organic fertilizers is reflected in the biodegradation rates of TPHs achieved by the systems treated with the pure or diluted algal extract and the system treated with synthetic fertilization. Results showed that TPH biodegradation rates were higher when synthetic fertilizers were used, which could be attributed to a faster increase in the bacterial population when having easily available nutrients.

In the systems treated with the pure and diluted algal extract, a similar biodegradation rate was observed, suggesting that the extract provides essential nutrients for bacterial growth. However, among these three systems, the one with the pure algal extract showed the highest biodegradation rate and a notable increase in microbial biomass.

The production of carbon dioxide observed in the soil treated with the pure algal extract and synthetic fertilizer would indicate the occurrence of biological degradation processes, that is, the transformation of organic molecules into simpler compounds through biological activity. Water and carbon dioxide are the end products of these degradation processes (Murphy, 2014). Therefore, biodegradation can be evaluated by measuring the degree of mineralization through the release of carbon dioxide.

Another factor to consider is the treatment time: if the treatment time is prolonged, higher biodegradation values could be achieved with the use of biofertilizers. Microorganisms present in biofertilizers are known to accelerate plant development by improving nutrient availability through mechanisms such as nitrogen fixation,

phosphorus solubilization, and iron absorption (Zainuddin et al., 2022).

The carbon chains that showed the highest biodegradation rates were those between C8 and C16. This could be because more complex chains, as well as aromatic and polar compounds, are more difficult to degrade due to their complex chemical nature (Pucci et al., 2003; López et al., 2021).

The pH of the soil was maintained at optimal values for biological activity. Soil pH has an important role in biodegradation because it influences microbial activity due to enzyme function, and impacts the diversity of the microbial community (Pucci et al., 2015; Myazin et al., 2021). To perform bioremediation processes, microbial communities must develop within specific pH ranges. This is because pH determines the degree of ion absorption by soil particles, which in turn influences their solubility, mobility and availability (Hidalgo, 2020).

The abundance of microorganisms indicated the presence of active aerobic processes in the soil, as well as the existence of bacteria with the ability to use hydrocarbons as a source of carbon and energy. This could be corroborated by using the n-C17/pristane and n-C18/phytane ratios as a method to compare biodegradation potentials. In this specific case, a decrease in the values of these ratios was observed in all systems, suggesting that the degradation observed was biological (Minai-Tehrani et al., 2015).

The use of fertilizers and biostimulation procedures can impact the microbial population (Kahraman et al., 2017; Pucci and Acuña et al., 2015). The addition of nutrients has been found to increase the number of microorganisms because it helps with nitrogen and phosphorus needs. Furthermore, maintaining a high density of bacteria is crucial for efficient bioremediation (Balseiro-Romero et al., 2019; Pucci et al., 2015; Acuña and Pucci, 2022).

5. Conclusion

The results of the present study demonstrate that bioremediation processes occurred in the oil drill cuttings studied. The TPH content was effectively reduced in all systems and the controls, with biodegradation being higher in the treatment with synthetic fertilizer. The incorporation of the algal extract as a biofertilizer allowed obtaining good results in the degradation of TPH. Thus, its use can contribute not only to the total or partial replacement of chemical fertilizers but also to exploring more sustainable, profitable, and environmentally friendly alternatives.

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