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PRODUCTION OF A RESIDUE-BASED BIOSTIMULANT FOR OIL-CONTAMINATED SOIL REMEDIATION

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Abstract

Oil contamination of soil represents a critical environmental challenge that significantly undermines soil productivity, disrupts microbial ecosystems, and contributes to long-term ecological damage. Traditional remediation techniques often rely on expensive, energy-intensive methods that are not sustainable or feasible in developing regions. This study focuses on the production of a novel biostimulant derived from readily available agricultural residues, aimed at accelerating the natural biodegradation processes within oil-contaminated soils. The biostimulant formulation includes composted plant residues such as wheat straw and cotton stalks, which are enriched with a specialized microbial consortium capable of degrading petroleum hydrocarbons. Laboratory-scale trials demonstrated that the biostimulant not only facilitated the breakdown of hydrocarbons but also improved critical soil parameters such as organic matter content and microbial biomass. These findings suggest that such residue-based biostimulants could provide an effective, eco-friendly, and economically accessible solution for soil remediation, especially in oil-impacted agricultural landscapes.

Keywords: biostimulant, oil pollution, soil recovery, petroleum hydrocarbons, biodegradation, microbial enhancement, agricultural waste

1. Introduction

The contamination of soil with petroleum-derived substances is a growing concern across the globe, especially in countries with active oil extraction and refining industries.

Crude oil and its derivatives contain complex mixtures of toxic and persistent hydrocarbons that can severely degrade soil quality, inhibit plant growth, and pose serious risks to human and animal health. In Turkmenistan and other oil-rich nations, large tracts of arable land have been rendered infertile due to accidental spills, leaks, and improper disposal of petroleum products.

Traditional approaches to remediation, including excavation, thermal desorption, or chemical treatments, although effective to some extent, are expensive and often detrimental to soil structure and biodiversity. Therefore, there is an urgent need to explore sustainable and low-cost alternatives that can restore soil health without causing additional environmental harm.

Biostimulation, as a form of bioremediation, involves the enhancement of indigenous or introduced microbial communities through the addition of organic matter, nutrients, or other amendments that stimulate the biodegradation of pollutants. When formulated from organic agricultural residues, such biostimulants serve dual purposes: they provide essential carbon and nutrients to support microbial growth, and they contribute to the restoration of soil physical and chemical properties.

This research aims to develop a residue-based biostimulant using local waste materials and evaluate its efficiency in remediating artificially oil-contaminated soils under controlled laboratory conditions. The expected outcome is the creation of a scalable solution that promotes both environmental sustainability and agricultural productivity.

2. Materials and Methods

2.1 Biostimulant Preparation

The biostimulant was developed using a blend of locally available agricultural residues, including wheat straw, cotton stalks, and livestock manure. These materials were first shredded and pre-treated through aerobic composting for 30 days, with periodic turning to ensure proper oxygenation and uniform decomposition. During composting, the temperature, moisture content, and C/N ratio were closely monitored to optimize microbial activity and nutrient retention.

After the compost reached maturity, it was inoculated with a microbial consortium comprising strains of *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Acinetobacter calcoaceticus*, which had been previously isolated from oil-polluted sites in the Balkan province of Turkmenistan. These strains were selected based on their demonstrated capacity to degrade various fractions of petroleum hydrocarbons.

2.2 Soil Contamination and Treatment Protocol

Clean sandy loam soil was collected from an uncontaminated site and sterilized to eliminate native microbial interference. The soil was then artificially contaminated with crude oil at a concentration of 5% (w/w) and thoroughly mixed to ensure homogeneity.

Three treatment groups were prepared: (1) soil treated with the residue-based biostimulant (10% w/w), (2) soil amended with non-inoculated compost, and (3) an untreated control.

The treated soils were incubated in laboratory conditions (25°C, 60% relative humidity) for a period of 60 days. Moisture levels were maintained at 60% field capacity throughout the experiment by regular addition of distilled water.

2.3 Analytical Procedures

At intervals of 0, 15, 30, and 60 days, soil samples were collected and analyzed for Total Petroleum Hydrocarbons (TPH) using gas chromatography coupled with flame ionization detection (GC-FID). Soil pH was measured with a glass electrode, and organic matter content was determined using the Walkley-Black method. Microbial biomass carbon (MBC) was quantified using the chloroform fumigation extraction technique. Statistical analysis was performed using ANOVA to assess significant differences between treatment groups.

3. Results and Discussion

The application of the residue-based biostimulant led to a significant reduction in Total Petroleum Hydrocarbons over the 60-day experimental period. Specifically, soils treated with the biostimulant exhibited a 65% decrease in TPH concentrations, compared to a 38% reduction in soils treated with non-inoculated compost and only 24% in the untreated control group. These results strongly indicate the enhanced biodegradation capabilities imparted by the microbial consortium and the organic matrix provided by the composted residues.

Further analysis revealed marked improvements in key soil parameters. The microbial biomass carbon in biostimulant-treated soils increased by 70%, suggesting a substantial stimulation of microbial growth and activity. Soil organic matter also increased, contributing to better nutrient retention, soil aggregation, and aeration. The pH of the treated soil remained within a neutral range, indicating that the treatment did not induce any significant acidification.

The enhanced degradation performance is likely attributable to the synergistic interaction between the organic substrate and the hydrocarbon-degrading microbes. The composted residues served as both a carrier and an energy source for the microbes, while also improving soil structure and oxygen diffusion—critical factors for aerobic biodegradation.

These findings are consistent with previous studies that highlight the importance of biostimulation strategies in the context of hydrocarbon remediation. Moreover, the use of locally sourced materials offers an economically viable option for farmers and landowners in oil-affected regions, enabling the adoption of remediation practices without reliance on imported chemicals or equipment.

4. Conclusion

The research demonstrates that a biostimulant derived from agricultural residues, when enriched with selected hydrocarbon-degrading microorganisms, can significantly accelerate the remediation of oil-contaminated soils. In addition to reducing pollutant levels, the treatment improves overall soil health by enhancing microbial activity and organic matter content.

This approach aligns with principles of circular economy and sustainable agriculture by turning agricultural waste into valuable bioproducts. The simplicity and cost-effectiveness of the method make it particularly suitable for large-scale deployment in rural and oil-affected areas of Turkmenistan and other regions with similar environmental challenges.

Future studies should focus on field-scale validation of the technology, long-term monitoring of soil recovery, and the exploration of other microbial strains and waste combinations to further enhance biostimulant efficacy.

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