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Phytoremediation of Petrol-Contaminated Soil Using Ficus Racemosa L. Amended with Poultry Droppings

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Abstract

Petroleum hydrocarbon contamination of agricultural and peri-urban soils is a persistent problem in oil-producing regions of Nigeria, yet plant species evaluated for its phytoremediation remain narrow, dominated by grasses and a few leguminous species. This study evaluated the phytoremediation potential of *Ficus racemosa* L., an ecologically and medicinally important woody species untested for this purpose, in petrol-contaminated soil amended with poultry droppings. Seedlings were grown for 12 weeks in soil contaminated with Premium Motor Spirit at approximately 4% (v/w) (initial TPH concentration 5000 mg kg^{-1}), in a Completely Randomized Design with an uncontaminated planted control, unplanted unamended and amended baselines, and planted unamended and amended treatments, replicated three times. Growth parameters, chlorophyll content, root length, TPH removal, and soil pH recovery were assessed. Unamended contamination severely suppressed growth and physiological parameters relative to the control; unplanted, unamended soil achieved only 18.00 ± 1.10% TPH removal after 12 weeks via natural attenuation. Poultry-droppings amendment and F. racemosa independently improved removal (48.00 ± 1.42% and 66.00 ± 1.35%), while their combination removed 87.00 ± 0.95%, reducing residual TPH to 650 ± 26 mg kg^{-1}. The combined treatment also restored soil pH from 5.20 ± 0.03 to 6.80 ± 0.04, matching the control, and produced growth, chlorophyll, and root-length values equalling or exceeding control values by Week 10. These findings identify F. racemosa as a previously untested, locally available candidate for petroleum-hydrocarbon phytoremediation, and show its combination with a low-cost, widely available organic amendment achieves faster, more complete remediation than either intervention alone.

Keywords: Phytoremediation; Ficus racemosa; petroleum hydrocarbon; poultry droppings; bioaugmentation; soil contamination

Abbreviation(s): TPH – Total Petroleum Hydrocarbon; PMS – Premium Motor Spirit; CRD – Completely Randomized Design; SPAD – Soil Plant Analysis Development (chlorophyll meter unit); DMRT – Duncan's Multiple Range Test

INTRODUCTION

Petroleum exploration, refining, transportation, and distribution activities have made hydrocarbon contamination of soil a persistent and widespread environmental problem, particularly in oil-producing regions such as the Niger Delta and other parts of Nigeria where spillage, pipeline vandalism, and improper disposal of petroleum products routinely introduce petrol, diesel, and crude oil into agricultural and peri-urban soils. Petroleum hydrocarbons alter soil physicochemical properties, reduce oxygen availability to roots, disrupt nutrient cycling, and are directly phytotoxic, commonly manifesting as reduced germination, stunted growth, chlorosis, and impaired root development in exposed vegetation (Haider *et al.*, 2021).

Phytoremediation, the use of plants, often in combination with their associated rhizosphere microbial communities, to extract, degrade, or stabilize soil contaminants has been widely promoted as a low-cost, ecologically sustainable alternative to physicochemical remediation methods such as excavation, incineration, or chemical washing (Correa-García *et al.,* 2018). Comparative work has shown that trees can be as effective as, or more effective than, grasses for rhizoremediation of petroleum hydrocarbons over longer time horizons, owing to their deeper and more extensive root systems and sustained rhizosphere microbial stimulation (Cook & Hesterberg, 2013). The efficiency of phytoremediation is frequently enhanced through soil amendment with organic materials such as animal manure, which supply nitrogen and phosphorus to stimulate hydrocarbon-degrading microbial populations while improving soil structure and moisture retention. Poultry manure in particular has been repeatedly shown to be an effective biostimulant: amendment at 10% w/w has been reported to drive total petroleum hydrocarbon elimination as high as 96.8% in impacted soil over 60 days (Osadebe & Nkoro, 2024), and comparative studies of animal-manure amendments have found poultry manure to outperform cattle manure in stimulating hydrocarbon degradation (Douglas *et al.,* 2024). Combining organic or mineral amendments with an actively growing plant rather than applying either intervention alone has separately been shown to enhance hydrocarbon removal beyond what phytoremediation or biostimulation achieve individually (Han *et al.*, 2016), and reviews of amendment-assisted phytoremediation have called for wider testing of specific plant–amendment combinations across contaminant and soil types (dos Santos & Maranho, 2018).

Despite this well-established general framework, the range of plant species evaluated for petroleum-hydrocarbon phytoremediation in the West African literature remains narrow, dominated by grasses such as vetiver (*Chrysopogon zizanioides*) and a limited number of leguminous cover crops. Woody species with additional ecological or economic value which could in principle deliver remediation alongside a secondary yield of ecological, medicinal, or resource benefit remain comparatively unexamined. *Ficus racemosa* L. (family Moraceae) is one such species: it is recognised for its ecological importance and for a wide range of traditionally documented medicinal uses, with numerous biologically active phytochemical constituents identified in its various plant parts (Ahmed & Urooj, 2010). To date, however, no published study has evaluated its tolerance of, or remediation capacity in, petroleum-contaminated soil, and none has tested it in combination with poultry droppings despite poultry droppings being one of the most widely available, low-cost organic waste materials in Nigerian agricultural systems.

This gap is the specific motivation for the present study: whether *Ficus racemosa* can tolerate and grow in petrol-contaminated soil, whether its remediation performance can be enhanced through poultry-droppings amendment, and how this combination compares with either intervention applied alone. This study therefore evaluated the phytoremediation potential of *Ficus racemosa* in petrol-contaminated soil amended with poultry droppings, assessing plant growth (height, leaf number, stem girth), physiological status (chlorophyll content), root development, total petroleum hydrocarbon removal, and soil pH recovery over a 12-week period under controlled conditions.

MATERIAL AND METHODS:

Study area

The experiment was conducted in the Botanical Garden and Green House of the Department of Plant Sciences, Akwa Ibom State University, Ikot Akpaden Campus, Mkpat Enin Local Government Area, Akwa Ibom State, Nigeria. The study area experiences a humid tropical climate with annual rainfall of approximately 2,000–3,000 mm, mean temperatures of 26–30°C, and relative humidity of 75–90%.

Plant material and soil preparation

Uniform, healthy *Ficus racemosa* seedlings (20–30 cm in height), free from visible disease or insect damage, were obtained from a reputable nursery within Akwa Ibom State. Surface soil (0–20 cm depth) was collected from an uncontaminated site within the university environment, cleared of stones, roots, and debris, air-dried for seven days, and sieved (2 mm) to obtain a uniform texture. Fresh poultry droppings were air-dried under shade for two weeks, crushed, and sieved (2 mm) before storage in polyethylene bags until use.

Soil contamination and amendment

Five kilograms of sieved soil were placed into each 10 L polyethylene planting bag. Soil designated for contamination was polluted with 200 mL of Premium Motor Spirit (PMS), corresponding to approximately 4% (v/w) contamination, mixed thoroughly, and left undisturbed for seven days to stabilize. Well-decomposed poultry droppings were incorporated into designated treatments at 250 g per 5 kg soil (5% w/w), mixed thoroughly seven days before transplanting to encourage microbial activity and nutrient release.

Experimental design and treatments

The experiment was arranged in a Completely Randomized Design (CRD) comprising five treatments replicated three times (15 experimental units): T1, uncontaminated soil planted with F. racemosa (control); T2, petrol-contaminated soil, unplanted and unamended (natural attenuation baseline); T3, petrol-contaminated soil, unplanted, amended with poultry droppings (biostimulation-only baseline); T4, petrol-contaminated soil planted with F. racemosa, unamended (phytoremediation only); and T5, petrol-contaminated soil planted with F. racemosa and amended with poultry droppings (combined bioaugmented phytoremediation). T2 and T3 were included to isolate the contribution of the plant itself from that of the organic amendment and of background microbial attenuation, and were monitored for soil chemistry only; T1, T4, and T5 were monitored for both plant growth and soil chemistry. Healthy F. racemosa seedlings were transplanted individually into each planted treatment bag, watered immediately, and maintained under natural environmental conditions with watering every two days. Weeds were removed manually from all treatments; no chemical pesticides were applied, to avoid interference with soil microbial activity relevant to phytoremediation.

Growth and physiological measurements

Plant height, stem girth (diameter), and number of leaves were recorded at two-week intervals for 12 weeks. Plant height was measured from the soil surface to the terminal bud using a metre rule; stem girth (diameter) was measured with a digital Vernier caliper; leaf area was estimated as Length × Width × 0.75. Chlorophyll content (SPAD units) was recorded at the terminal assessment. At harvest, root length was measured, and fresh biomass was weighed immediately using an electronic balance; dry biomass was determined after oven-drying at 70°C to constant weight.

Soil analysis and phytoremediation efficiency

Composite soil samples were collected before contamination and after harvest for determination of particle size distribution, bulk density, moisture content, pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and total petroleum hydrocarbons (TPH). TPH was determined by standard extraction and spectrophotometric/gas-chromatographic methods. Percentage TPH removal was calculated as: TPH Removal (%) = [(Initial TPH − Final TPH) / Initial TPH] × 100.

Statistical analysis

Data were subjected to one-way analysis of variance (ANOVA) using SPSS version 27. Treatment means were separated using Duncan's Multiple Range Test (DMRT) at $P < 0.05$. Results are presented as mean ± standard error.

RESULT AND DISCUSSION:

Result:

Growth and physiological parameters (plant height, stem girth, leaf number, chlorophyll content, root length) are reported for the three planted treatments (T1, T4, T5); T2 and T3 were unplanted and were monitored for soil chemistry only. Total petroleum hydrocarbon removal and soil pH recovery are reported for all relevant treatments (T2–T5 for TPH; T1–T5 for pH).

Plant height, stem girth, and leaf number all increased progressively across the three planted treatments from Week 2 to Week 10 (Table 1; Figure 1). The uncontaminated control (T1) grew normally, while unamended contaminated soil (T4) trailed throughout on all three parameters, confirming the inhibitory effect of petrol contamination even where the plant itself was present. The combined treatment (T5) overtook the control from around Week 6 onward on all three parameters, reaching 46.20 ± 0.82 cm in height, 12.30 ± 0.30 mm in stem girth, and 49.00 ± 1.67 leaves by Week 10 — the highest values recorded for any treatment.

Table 1: Effect of Treatments on Growth Parameters of *Ficus racemosa* Over 12 Weeks

Week	Height (cm): T1 / T4 / T5	Girth (mm): T1 / T4 / T5	Leaves: T1 / T4 / T5
2	12.40 / 8.20 / 9.50	3.80 / 2.80 / 3.10	10.0 / 7.0 / 8.0
4	18.70 / 14.80 / 17.30	5.70 / 4.60 / 5.40	18.0 / 14.0 / 17.0
6	26.50 / 22.50 / 26.80	7.90 / 6.80 / 8.00	28.0 / 23.0 / 27.0
8	34.80 / 30.20 / 36.40	9.80 / 8.90 / 10.40	37.0 / 32.0 / 39.0
10	42.30 / 38.60 / 46.20	11.50 / 10.80 / 12.30	45.0 / 41.0 / 49.0

[Standard errors omitted from this merged table for space; ranged ±0.27–0.85 (height), ±0.08–0.30 (girth), ±0.33–1.67 (leaves); see Figure 1 for error bars.]

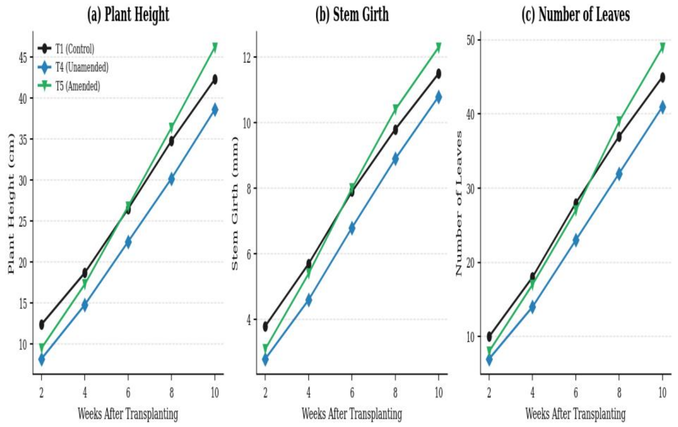

Figure 1: Effect of Treatments on (a) Plant Height, (b) Stem Girth, and (c) Number of Leaves of *Ficus racemosa* Over 12 Weeks

Chlorophyll content (SPAD units) at final assessment was lowest in unamended contaminated soil (T4: 35.60 ± 0.73) and highest in the combined treatment (T5: 43.80 ± 0.81), which slightly exceeded the uncontaminated control (T1: 41.60 ± 0.84). Root length showed a comparable pattern: shortest in unamended contaminated soil (T4: 24.80 ± 0.55 cm) and longest in the combined treatment (T5: 30.60 ± 0.63 cm), which again exceeded the uncontaminated control (T1: 27.60 ± 0.58 cm) (Table 1; Figure 2)

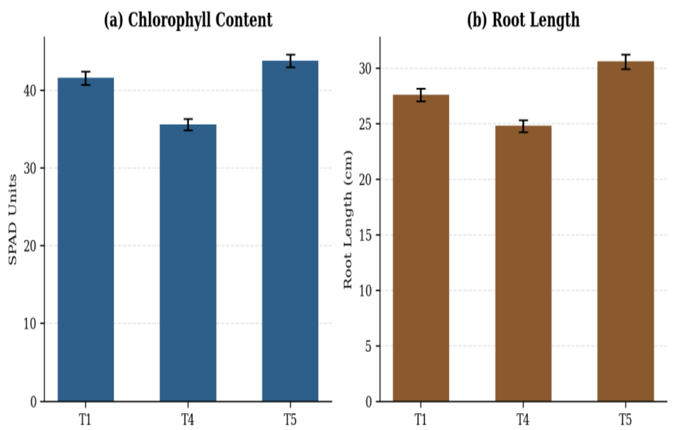

Figure 2: Effect of Treatments on (a) Chlorophyll Content and (b) Root Length of *Ficus racemosa*

Total petroleum hydrocarbon removal differed markedly among the four contaminated treatments (Table 2; Figure 3a), all of which began at 5000 ± 0.00 mg kg^{-1}. The unplanted, unamended baseline (T2) achieved only 18.00 ± 1.10% removal through natural attenuation alone (final: 4100 ± 54 mg kg^{-1}). Amendment with poultry droppings without a plant (T3) raised removal to 48.00 ± 1.42% (final: 2600 ± 48 mg kg^{-1}), while F. racemosa without amendment (T4) achieved a higher 66.00 ± 1.35% (final: 1700 ± 37 mg kg^{-1}) — indicating that, in this system, the plant's rhizoremediation contribution exceeded that of manure-driven biostimulation alone. The combined treatment (T5) achieved the greatest removal by a wide margin, 87.00 ± 0.95% (final: 650 ± 26 mg kg^{-1}), exceeding the sum of the two individual effects relative to the unplanted, unamended baseline and indicating a synergistic rather than purely additive interaction between plant and amendment.

Table 2: Total Petroleum Hydrocarbon (TPH) Concentration and Removal by Treatment

Treatment	Initial (mg kg^{-1})	Final (mg kg^{-1})	Removal (%)
T2 (Unplanted, unamended)	5000 ± 0.00	4100 ± 54	18.00 ± 1.10
T3 (Unplanted, amended)	5000 ± 0.00	2600 ± 48	48.00 ± 1.42
T4 (Planted, unamended)	5000 ± 0.00	1700 ± 37	66.00 ± 1.35
T5 (Planted, amended)	5000 ± 0.00	650 ± 26	87.00 ± 0.95

Soil pH, depressed by petrol contamination from a starting point near 5.20 in all contaminated treatments, recovered to varying degrees by harvest (Table 3; Figure 3b). The combined treatment (T5) produced the greatest recovery, from 5.20 ± 0.03 to 6.80 ± 0.04, matching the uncontaminated control (T1: 6.80 ± 0.03 to 6.90 ± 0.04), while the unplanted, unamended baseline (T2) showed minimal recovery (5.20 ± 0.04 to 5.40 ± 0.05).

Table 3: Soil pH Before and After Treatment

Treatment	Initial pH	Final pH
T1 (Control)	6.80 ± 0.03	6.90 ± 0.04
T2 (Unplanted, unamended)	5.20 ± 0.04	5.40 ± 0.05
T3 (Unplanted, amended)	5.20 ± 0.03	6.20 ± 0.06
T4 (Planted, unamended)	5.20 ± 0.04	6.40 ± 0.05
T5 (Planted, amended)	5.20 ± 0.03	6.80 ± 0.04

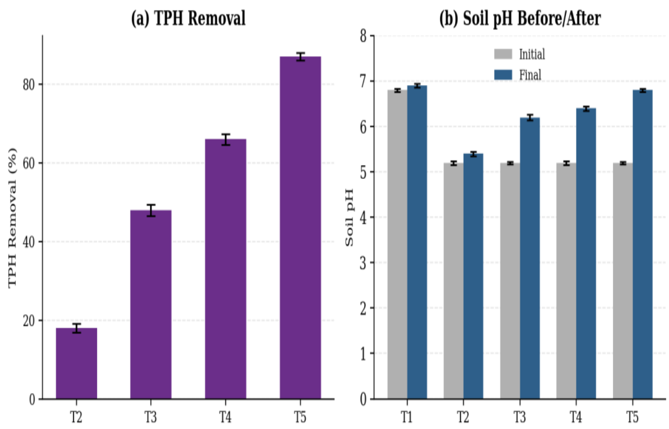

Figure 3: (a) Total Petroleum Hydrocarbon Removal and (b) Soil pH Before and After Treatment

Discussion:

The suppression of growth, chlorophyll content, and root development observed under unamended petrol-contaminated soil (T4) relative to the uncontaminated control (T1) is consistent with the well-documented phytotoxicity of petroleum hydrocarbons, which restrict root-zone oxygen availability, disrupt nutrient uptake, and interfere with photosynthetic pigment synthesis and function (Haider *et al.,* 2021). The very low TPH removal recorded in the unplanted, unamended baseline (T2: 18.00 ± 1.10%) reflects the limited capacity of natural attenuation relying only on the soil's indigenous, contamination-suppressed microbial community, without either rhizosphere stimulation or nutrient amendment to degrade hydrocarbons over the 12-week period.

The improvement in TPH removal under poultry-droppings amendment without a plant (T3: 48.00 ± 1.42%) corroborates a substantial body of evidence that poultry manure is an effective biostimulant for hydrocarbon-degrading soil microorganisms, supplying nitrogen and phosphorus that are frequently limiting in contaminated soils and thereby relieving the nutrient constraint on microbial hydrocarbon catabolism (Ezenne *et al.,* 2014; Osadebe & Nkoro, 2024). Reported TPH elimination under poultry-manure amendment elsewhere has ranged widely, from roughly 36% to over 96% depending on manure loading rate, contamination level, and duration (Douglas *et al.*, 2024; Osadebe & Nkoro, 2024), situating the present result within a plausible range for the amendment rate and timeframe used here. The still greater removal achieved by F. racemosa without amendment (T4: 66.00 ± 1.35%) indicates that, in this system, the plant's own rhizoremediation contribution exceeded that of manure-driven biostimulation alone — consistent with evidence that rhizoremediation by woody species can match or exceed grass-based and purely microbial approaches over comparable timeframes (Cook & Hesterberg, 2013), likely reflecting sustained root-exudate release and the establishment of a hydrocarbon-degrading rhizosphere microbial community around an actively growing root system, an effect unavailable to the unplanted T2 and T3 treatments.

The markedly greater removal achieved by the combined treatment (87.00 ± 0.95%) than by either intervention alone indicates a synergistic rather than merely additive effect, consistent with reports that combining organic amendment with an actively growing plant enhances hydrocarbon degradation beyond either intervention individually (Han *et al.,* 2016), most plausibly because poultry-droppings amendment relieved the nutrient limitation on microbial activity while the F. racemosa root system simultaneously improved soil aeration, supplied labile root exudates, and provided expanded rhizosphere surface area for degrader colonization. The parallel recovery of soil pH toward near-neutral values under the combined treatment further supports this interpretation: manure amendment is known to buffer and neutralize the mild acidification associated with hydrocarbon contamination (Whalen *et al.,* 2000), and the pH trajectory observed here tracked TPH removal closely across treatments, consistent with soil pH recovery and hydrocarbon degradation being mechanistically linked through restored microbial activity.

Perhaps the most notable finding is that combined-treatment plants (T5) matched or exceeded uncontaminated control (T1) performance in chlorophyll content and root length by the end of the study, despite starting from the same severe contamination burden as the other petrol-treated groups. This suggests that, once nutrient limitation was relieved by manure amendment, the combination of ample nutrient supply with an actively degrading rhizosphere may have produced growing conditions that were, on balance, more favourable than those in the unamended uncontaminated control, an outcome with direct practical relevance for remediation programmes seeking to demonstrate not merely contaminant removal but productive, revegetated end-states. This result should nonetheless be interpreted with appropriate caution pending replication, given its departure from the general expectation that contaminated-soil treatments would, at best, approach but not exceed control performance.

CONCLUSION:

Ficus racemosa demonstrated clear tolerance of, and phytoremediation capacity in, petrol-contaminated soil, and its combination with poultry-droppings amendment produced substantially greater total petroleum hydrocarbon removal (87%) than either the plant or the amendment applied alone, alongside full recovery of soil pH and plant growth performance matching or exceeding an uncontaminated control. These findings identify F. racemosa as a viable, previously untested candidate species for phytoremediation programmes in petroleum-impacted soils, and support poultry-droppings amendment as a low-cost, locally available strategy for enhancing such programmes in Nigerian agricultural and peri-urban contexts.

RECOMMENDATION(S):

It is recommended that

I. field-scale trials be conducted to validate these controlled-environment findings under natural soil and weathering conditions.

II. future work extends the assessment to a wider range of contamination levels and amendment rates to establish dose–response relationships.

III. the microbial community composition and enzymatic activity of the rhizosphere be characterized directly to clarify the mechanistic basis of the observed synergy between *F. racemosa* and poultry-droppings amendment.

IV. The unexpectedly strong performance of the combined treatment relative to the uncontaminated control on chlorophyll content and root length be independently replicated before being generalized, given its departure from the more typical expectation that contaminated-soil treatments would, at best, approach but not exceed control performance.

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FOOTNOTE(S):

Not applicable.

TABLE/CHART:

Table 1: Effect of Treatments on Growth Parameters of Ficus racemosa Over 12 Weeks

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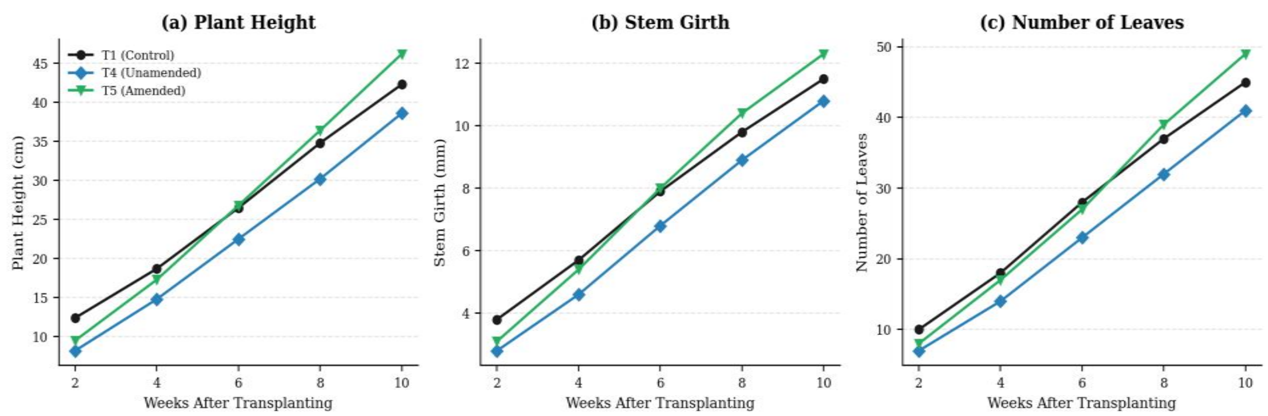
FIGURE/GRAPH/MAP/LAYOUT/OUTLINE:

Figure 1: Effect of Treatments on (a) Plant Height, (b) Stem Girth, and (c) Number of Leaves of Ficus racemosa Over 12 Weeks



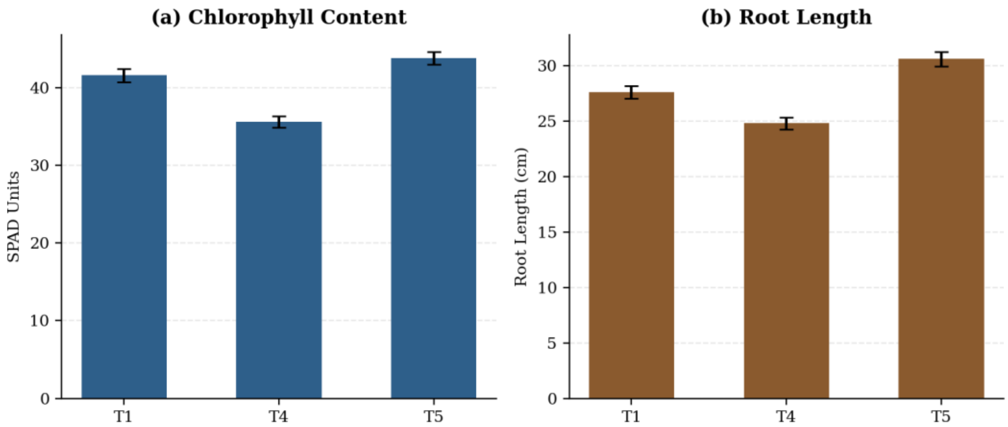
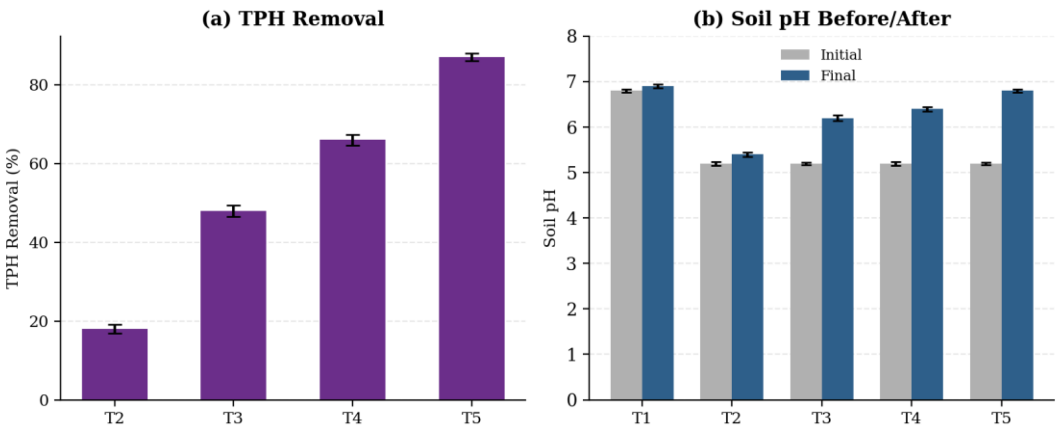


Figure 2: Effect of Treatments on (a) Chlorophyll Content and (b) Root Length of Ficus racemosa



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