The Impact of Forest Fire on Soil Phytotoxicity in the Cedar and Fir Reserve, Northwestern Lattakia, Syria

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Received: 16/ 02/2026 **Accepted:** 8/04 /2026

Abstract

This study aimed to determine the degree of soil phytotoxicity in the Cedar and Fir Reserve (Slinfah area, Lattakia, Syria) following the 2020 wildfire. Phytotoxicity was used as an effective bio indicator to assess soil measuring biological activity in fire-affected soils. Soil samples were collected from the eastern slope of the reserve three years after the fire at two depths (0–10 cm and 10–30 cm). The sample included all fire-severity levels (low, moderate and high), in addition to unburned sites used as controls. The results revealed high phytotoxicity in soils exposed to high-severity fires, as evidenced by significant inhibition of root and shoot growth. Root and shoot lengths decreased by 40% and 52%, respectively, while root biomass declined by 29% compared with the control. This reduction may be attributed to the formation of toxic organic compounds that inhibit root elongation due to partial thermal decomposition of organic matter at elevated temperatures.

In contrast, low-severity fires appeared to stimulate root and shoot growth, likely due to the release of nutrients from post-fire ash. The study also showed no significant effect of soil depth on root or shoot length, whereas depth had a significant effect on root biomass.

Keywords: Wildfire, Soil phytotoxicity, bioindicators, Cedar and Fir Reserve, fire severity.

Introduction:

Soil is one of the most important natural resources, supporting a wide range of ecological and socio-ecological systems (Alcaniz et al., 2018). It plays a crucial role in nutrient cycling as a major reservoir of minerals and nutrients, contributes to carbon sequestration, and supports plant growth (Osman, 2013). On human time scales, soil is considered a non-renewable resource due to its rapid degradation and extremely slow formation (Lal, 2015). Major drivers of soil degradation in forest ecosystems include deforestation, wildfires, and soil pollution (Ghazoul et al., 2015; Silvério et al., 2019).

Wildfires represent an increasing threat to the integrity of forest ecosystems. The rapid decline in forest area and the irreversible loss of natural forests have made wildfires a major risk factor influencing atmospheric processes and climatic conditions.

Forest fires alter the biological, physical, and chemical properties of soil and reduce nutrient stocks through processes such as volatilization, oxidation, and erosion (Pellegrini et al., 2018). They also promote the accumulation of toxic compounds, including heavy metals and organic combustion products, which can exert phytotoxic effects by inhibiting seed germination and reducing root growth. Following fire, these compounds may shift from stable to more mobile forms, increasing their uptake by plants and thereby elevating phytotoxicity levels. Because such changes cannot be fully captured through chemical analyses alone, researchers increasingly rely on biological indicators, such as

phytotoxicity, to assess the actual impact of contaminants on soil biological properties (Barroso et al., 2021).
Soil phytotoxicity refers to the toxic effects of substances on plant growth. According to Barroso et al. (2021), a wide range of compounds can cause damage when plants are unable to immobilize or detoxify excessive concentrations of organic or inorganic pollutants.
Phytotoxicity tests are widely used bioassays for evaluating soil contamination, based on indicators such as seed germination percentage (SG%) and root inhibition index (RI%) in higher plants grown in contaminated soil for at least 72 h under controlled conditions (darkness, 25 °C), following standardized protocols (MicroBio Tests Inc., 2014). Results are compared with control samples grown in reference soil.
These assays are effective for assessing fire impacts on soils. Growth measurements serve as key bioindicators, with the root system (length and biomass) being the most sensitive due to direct contact with contaminants. Root inhibition reflects early toxic effects, while shoot growth indicates overall plant development.
Comparing these parameters between burned or contaminated soils and control samples, together with chemical analyses, provides a comprehensive toxicity profile that helps identify the actual biological effects of fire residues on plant vitality and health (Zabaleta et al., 2024).
For instance, Barroso et al. (2021) evaluated post-fire soil biological status using phytotoxicity tests with model plant species such as Lepidium sativum and Sinapis alba. Seeds grown in fire-affected soils exhibited varying degrees of phytotoxicity depending on fire severity and sampling depth, indicating that combustion residues may reduce soil fertility and limit plant growth.
Similarly, Memoli et al. (2019) assessed fire-affected Mediterranean volcanic soils using phytotoxicity indices based on germination and root length of Lepidium sativum, Sinapis alba, and Sorghum saccharatum. Their results showed significant reductions in germination and growth in burned soils, reflecting toxic effects associated with fire-induced chemical changes. These findings confirm that phytotoxicity tests are rapid and sensitive bioindicators for evaluating ecological recovery and identifying the need for restoration interventions.

Significance and Objectives:

Significance of the study:

This study evaluates the impact of the 2020 wildfire on soil biological functioning in the Cedar and Fir Reserve using phytotoxicity indices as indicators of biological recovery several years after the fire. It also examines variations in biological responses across different fire-severity levels and soil depths.

Objectives:

The main objective was to assess phytotoxicity in fire-affected soils of the Cedar and Fir Reserve compared with unburned soils. This was achieved by measuring inhibition of root and shoot growth and changes in root biomass under different fire severities and soil depths.

Materials and Methods:

Study Area:

The Cedar and Fir Reserve is a protected natural area officially designated on 22 July 1996 to conserve key plant species and support scientific research and ecotourism while maintaining ecosystem integrity. The reserve covers approximately 1,350 ha.
It is located in the coastal mountain range of northwestern Syria on the eastern and western slopes of Mount Nabi Matta and is administratively affiliated with the Slinfah district in Lattakia Governorate. The reserve extends between 35.29°–35.41° N and 36.10°–36.17° E.

The reserve is bordered to the north by the Slinfah–Broadcast Station–Al-Ghab road, to the south by the Abraj cadastral area, to the west by the main Slinfah–Jouba Brghal road, and to the east by the Jourin Al-Rayhaniyah cadastral area Fig (1).

Figure (1): Location and Boundaries of the Cedar and Fir Natural Reserve, Lattakia, Syria.

Elevation ranges from 900 to 1,560 m above sea level, with the lowest elevation recorded at Jubb Al-Fir. The eastern slope is steep, reaching inclinations of up to 35°, whereas the western slope is moderately inclined (20–27°) (Biodiversity Conservation Project, 2004).

Soil Characteristics:

The parent material of the Cedar and Fir Reserve consists mainly of Jurassic limestone and dolomite formations overlooking the Al-Ghab Rift Valley. These rocks are highly fractured and are overlain by Mediterranean red soils developed under forest vegetation, local climatic conditions, and topography, forming characteristic forest soils.

At higher elevations, soils are richer in partially decomposed organic matter and are classified as humic calcareous soils, whereas at lower elevations they grade into Mediterranean brown soils. The soils generally exhibit high organic matter content and vary in depth from approximately 15 cm to more than 1 m. In many locations, hard calcareous bedrock occurs close to the surface (Ruqayyah *et al*., 2006).

Sampling Design and Soil Collection:

Selection of Sampling Sites:

Sampling locations were determined using a spatial fire-severity map generated after the 2020 wildfire in the Cedar and Fir Reserve (Karmo *et al*., 2022). The map indicated substantial variability in fire severity across the reserve, with high-severity burns concentrated on the eastern slope, whereas the western slope was classified as low-severity or unburned Fig (2).

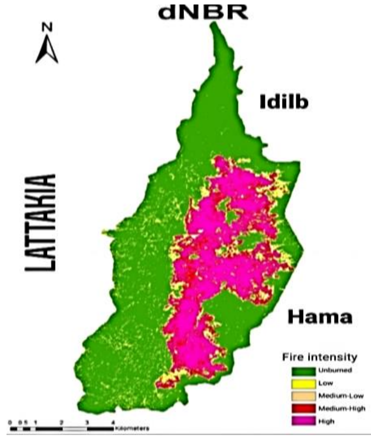

Figure (2): Fire Severity Levels and Their Spatial Distribution in the Cedar–Fir Natural Reserve.

Sites were selected to represent all fire-severity levels while maintaining comparable vegetation cover between burned and unburned areas. The geographic coordinates of each sampling location were recorded using a GPS device Table (1).

Table (1): Sampling sites and fire severity classes in the Cedar–Fir Natural Reserve (2020 wildfire).

Sample No.	Fire Severity Class	Coordinates
1	Unburned	35°59'71.447"N/ 35°22'59.471"E
2	Low	35°59'38.866"N/ 36°22'66.860"E
3	Low–Moderate	35°61'38.795"N/ 36°25'85.085"E
4	High–Moderate	35°59'64.668"N/ 36°22'64.926"E
5	High	35°59'39.778"N/ 36°22'73.381"E

Soil Sampling Procedure:

A total of ten soil samples were collected from the eastern slope of the reserve in 2023. Each sample weighed approximately 10 kg, with two replicate samples collected for each fire severity class (high, moderate–high, moderate–low, and low severity). Soil samples were collected from two depths:

- **Surface layer (0–10 cm):** representing the biologically active soil horizon most directly affected by fire.
- **Subsurface layer (10–30 cm):** to assess post-fire changes in biological efficiency with soil depth.

Control samples were collected from unburned sites on the same slope to evaluate background conditions. All samples were stored in labeled plastic bags indicating sample number and coordinates and transported to the laboratory for analysis.

Laboratory Analysis:

Laboratory analyses were conducted at the Faculty of Agricultural Engineering, University of Lattakia, following standard ecological and soil science methodologies (Methods of Soil Microbiology..., 1991).

Soil phytotoxicity was assessed under controlled laboratory conditions using a plant bioassay to evaluate soil biological functioning after wildfire disturbance. Phytotoxicity indicators included root length, shoot length, and root biomass, with results expressed as percentage variation relative to control samples.

Raphanus sativus (radish) was selected as the test species due to its high sensitivity, seed purity (98%), and germination rate (75%). A total of 30 Petri dishes were prepared, with three replicates per sample. Each dish contained 50 g of soil and was sown with 20 radish seeds arranged in four rows (five seeds per row). Soils were moistened with distilled water and incubated under controlled conditions, with regular moisture maintenance throughout the experiment. Measurements were taken 10 days after sowing. In addition to phytotoxicity tests, soil pH and organic matter content were determined for all samples (Table 2).

Table (2): pH values of the collected soil samples according to fire severity.

Sample No.	Fire Severity Class	pH
1	Unburned	6.1
2	Low	6.8
3	Low–Moderate	6.5
4	High–Moderate	7.2
5	High	7.1

Statistical Analysis:

Data were analyzed using one-way analysis of variance (ANOVA) to evaluate the effects of fire severity and soil depth on shoot length, root length, and root biomass. Statistical significance was assessed at $p \leq 0.05$.

Results and Discussion:

1. *Effects of fire severity and soil depth on shoot growth:*

Fire severity significantly influenced shoot development in Raphanus sativus grown in soils from the Cedar and Fir Reserve ($p = 0.027$; Fig. 3). Soils affected by high- and moderate–high-severity fires exhibited marked reductions in shoot length compared with unburned controls. Specifically, mean shoot length decreased by approximately 50–52% under high-severity conditions and by 29–33% under moderate–high severity, indicating pronounced phytotoxic effects associated with intense burning.

The inhibition of shoot growth in high-severity soils is likely attributable to fire-induced chemical alterations, including the formation of toxic organic compounds and elevated concentrations of mobile metals. High temperatures during severe fires promote partial thermal decomposition of soil organic matter, generating phytotoxic substances that impair plant development and reduce aboveground biomass.

In contrast, soils exposed to low and moderate–low fire severity exhibited a stimulatory effect on shoot growth. Mean shoot length increased by approximately 9–11% in moderate–low severity soils and by 20–47% in low-severity soils relative to unburned controls. This stimulatory response aligns with the well-documented fertilization effect of low-intensity fires, which enhance nutrient availability through ash deposition and accelerated mineralization of organic matter.

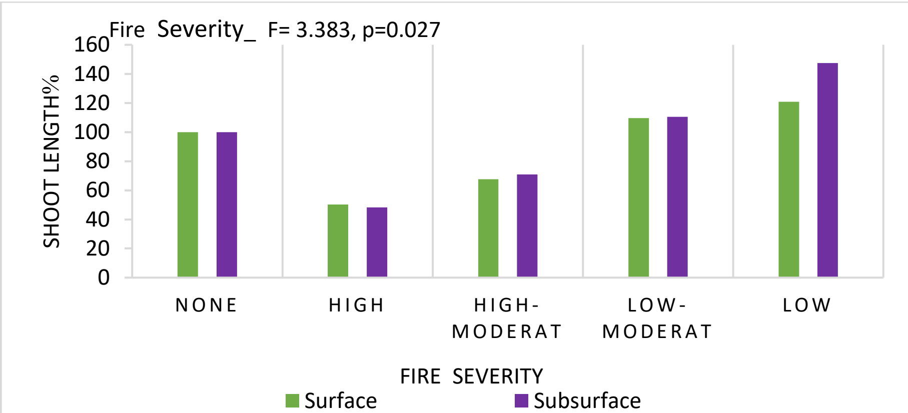

Figure (3): Changes in shoot length in soils of the Cedar and Fir Reserve according to fire severity and soil depth.

These findings are consistent with previous studies showing that low-severity fires can promote early plant growth by increasing the availability of macronutrients such as potassium, calcium, and magnesium, whereas high-severity fires create inhibitory conditions due to toxic residue accumulation and structural degradation of soil (Suárez-Ronay *et al*., 2024).

No statistically significant effect of soil depth on shoot length was observed, suggesting that fire severity, rather than vertical position within the soil profile, is the primary driver of aboveground growth responses (Fig. 3).

2. *Effects of fire severity and soil depth on Root Growth:*

Root growth proved more sensitive to fire-induced soil changes than shoot growth, confirming its value as an early indicator of soil phytotoxicity. High-severity and moderate–high-severity fire treatments resulted in substantial inhibition of root elongation. Mean root length decreased by approximately 33–40% under high severity and by 16–23% under moderate–high severity compared with unburned soils Fig (4).

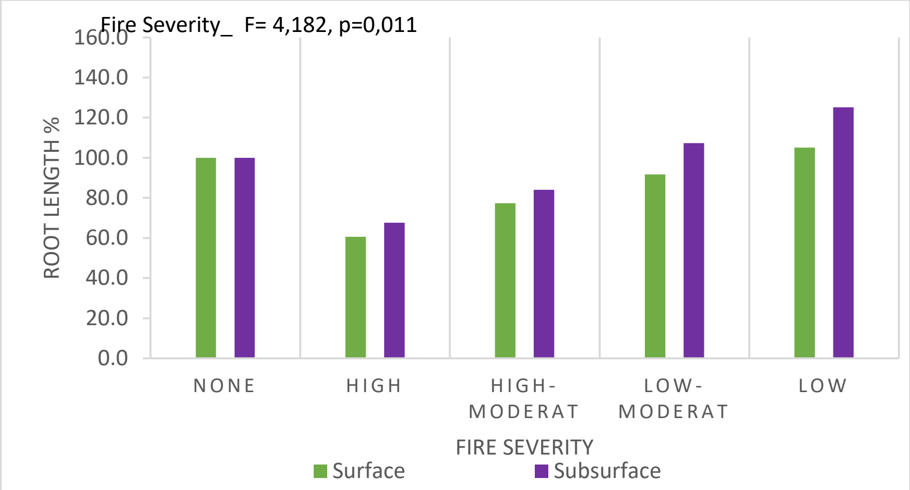

Figure (4): Changes in root length in soils of the Cedar and Fir Reserve according to fire severity and soil depth.

The suppression of root growth in these treatments likely reflects the accumulation of phytotoxic compounds produced during the combustion of organic matter. Thermal degradation processes can generate phenolic compounds, polycyclic aromatic hydrocarbons (PAHs), and other toxic substances that interfere with cell division and elongation in root tissues. These compounds may also increase metal mobility and reduce microbial activity, further limiting nutrient uptake (Kazeev *et al*.,2019).

Comparable findings have been reported in Mediterranean and temperate forest ecosystems, where high-severity fires have been associated with strong inhibitory effects on root growth due to chemical toxicity and structural degradation of soils (Memoli *et al*., 2019; Mesquita *et al*., 2022).

Conversely, moderate–low and low-severity fires stimulated root growth, with mean root length increasing by approximately 7–25% relative to control soils. This shift from inhibition to stimulation reflects the balance between nutrient release and toxic compound formation. Under low-severity conditions, partial combustion of litter layers leads to rapid nutrient mineralization without generating high concentrations of toxic residues. Increased soil pH and the release of base cations from ash further enhance nutrient availability and root uptake capacity.

Statistical analysis confirmed a significant effect of fire severity on both shoot length ($F(4, 22) = 3.383$, $p = 0.027$) and root length $F(4, 22) = 4.182$, $p = 0.011$). In contrast, soil depth had no significant effect on these parameters, indicating that fire severity was the dominant factor controlling early plant growth responses.

3. *Effects on Root Biomass:*

Root biomass exhibited strong sensitivity to both fire severity and soil depth. High-, moderate–high, and moderate–low fire treatments caused significant reductions in root biomass compared with unburned soils, with decreases ranging from approximately 7% to 29%, the most pronounced decline occurring under high-severity conditions. These reductions can be attributed to multiple interacting mechanisms: the complete combustion of organic matter reduces nutrient availability; structural degradation of soil aggregates impairs root anchorage and water retention; microbial activity is diminished, further limiting nutrient cycling; and the accumulation of phytotoxic residues creates unfavorable chemical conditions for root growth. Collectively, these factors severely constrain root development and biomass accumulation.

In contrast, low-severity fire treatments resulted in modest increases in root biomass (approximately 4–17%), reflecting enhanced nutrient availability and preservation of soil structure. Low-intensity burning can improve soil fertility by releasing nutrients while maintaining sufficient organic matter and microbial activity to support plant growth Fig. (5).

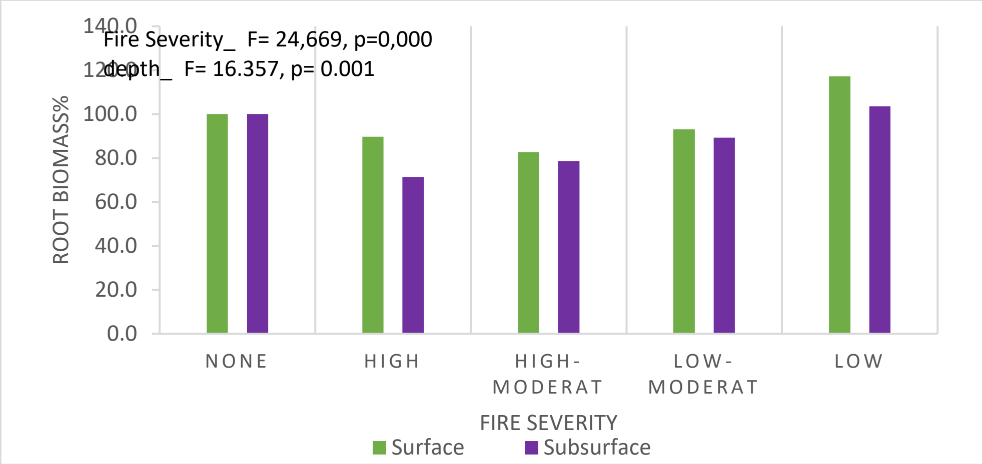

Figure (5): Changes in root biomass in soils of the Cedar and Fir Reserve according to fire severity and soil depth

ANOVA results confirmed that fire severity was the strongest predictor of root biomass variation ($p < 0.00018$), followed by soil depth ($p = 0.001$). The significant effect of soil depth suggests that soluble toxic compounds may move downward following fire, increasing phytotoxicity in subsurface layers and thereby limiting root growth at depth.

Sensitivity of Phytotoxicity Indicators:

All tested bioindicators demonstrated high sensitivity to fire-induced soil changes. Among the measured parameters, sensitivity followed the order: **root biomass < root length < shoot length**

Root-based indicators were particularly responsive to fire-induced toxicity, confirming their suitability as early diagnostic tools for assessing post-fire soil recovery. Integrating phytotoxicity assays with chemical and microbiological analyses can provide a comprehensive understanding of post-fire soil health and ecological resilience.

Conclusions:

Soils in the Cedar and Fir Reserve exhibited variable biological responses depending on fire severity and soil depth. High-severity fires produced strong phytotoxic effects, significantly inhibiting root and shoot growth and reducing root biomass. In contrast, low-severity fires stimulated plant growth, likely due to increased nutrient availability and improved soil chemical conditions.

Fire severity emerged as the primary driver of phytotoxic responses, while soil depth played a secondary but significant role in determining root biomass patterns. The results confirm the effectiveness of phytotoxicity indicators as sensitive tools for assessing post-fire soil recovery.

Recommendations:

1. Integrate phytotoxicity assays with additional biological indicators, including microbial activity, enzymatic activity, and soil respiration, to achieve a more comprehensive and multidimensional assessment of post-fire soil health.
2. Implement long-term monitoring programs to track soil recovery trajectories, evaluate the persistence of toxic residues, and guide evidence-based restoration and management strategies.
3. Consider the controlled application of low-severity prescribed burns in dense forest stands with nutrient-poor soils to enhance nutrient cycling and improve soil fertility, while carefully assessing potential ecological risks and ensuring ecosystem resilience.

References:

Alcaniz, M.; L. Outeiro; M. Francos; J. Farguell; and X. Ubeda (2016). Longterm dynamics of soil chemical properties after a prescribed fire in a Mediterranean forest (Montgri Massif, Catalonia, Spain). Sci Total Environ. 572: 1329–1335.

Barroso, P. M.; M. D. Vaverková; and J. Elbl (2021). Assessing the ecotoxicity of soil affected by wildfire. *Environments*, 8: 3.

Biodiversity Conservation and Protected Areas Management Project SY. GE. 57109 (2004). *Biodiversity conservation and protected areas management project*. 65 pages (in Arabic).

Ghazoul, J.; Z. Burivalova; J. Garcia-Ulloa; and L. A. King (2015). Conceptualizing forest degradation. *Trends in Ecology & Evolution*, 30: 622–632.

Karmo, A.; H. Al-Kateb; Z. Hamed; A. Salloum; A. Anter; and R. Daoud (2022). Classification of fire intensity levels in 2020 in the Cedar and Fir Nature Reserve in Syria using the standard NBR fire index. In: *Biological Diversity and Bioresources of the Steppe Zone Under Changing Climate Conditions: Proceedings of the International Scientific Conference dedicated to the 95th anniversary of the Botanical Garden of the Southern Federal University*, pp. 623–634. Southern Federal University Publishing House. ISBN 978-5-9275-4147-8.

Kazeev, K. Sh.; T. A. Poltoratskaya; A. S. Yakimova; M. Y. Odobashyan; A. K. Shkhapatsev; and S. I. Kolesnikov (2019). Post-fire changes in the biological properties of the brown soils in the Utrish State Nature Reserve (Russia). *Nature Conservation Research*, 4: 93–104.

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability. 7 (5): 5875–5895.

Memoli, V.; S. C. Panico; F. Esposito; R. Barile; A. De Marco; and G. Maisto (2019). Volcanic soil phytotoxicity in a burnt Mediterranean area. *Catena*, 183: 104181.

Mesquita, A. F.; N. Abrantes; I. Campos; C. Nunes; M. A. Coimbra; F. J. Goncalves; and A. M. Goncalves (2022). Effects of wildfire ash on the growth and biochemical profiles of the aquatic macrophyte *Lemna minor*. *Aquatic Toxicology*, 250: 106245.

MicroBioTests Inc. (2014). *Phytotoxkit: Seed germination and early growth microbiotest with higher plants; Standard operation procedure*. Nazareth, Belgium.

Osman, K. T. (2013). Forest soils. Soils. Springer, Dordrecht. pp. 229–251.

Pellegrini, A. F.; A. Ahlstrom; S. E. Hobbie; P. B. Reich; L. P. Nieradzik; A. C. Staver; B. C. Scharenbroch; A. Jumpponen; W. R. Anderegg; J. T. Randerson; and R. B. Jackson (2018). Fire frequency drives decadal changes in soil carbon and nitrogen and ecosystem productivity. *Nature*, 553: 194–198.

Ruqayyah, M.; H. Dabit; Y. Idris; R. Kasouha; and M. Bouhassoun (2006). Using remote sensing techniques in studying the Cedar and Fir Reserve in Lattakia Governorate (Slanfah). General Authority for Remote Sensing (in Arabic).

Silverio, D. V.; P. M. Brando; M. M. Bustamante; F. E. Putz; D. M. Marra; S. R. Levick; and S. E. Trumbore (2019). Fire, fragmentation, and windstorms: a recipe for tropical forest degradation. *Journal of Ecology*, 107: 656–667.

Suárez-Ronay, S. H.; S. Medina-Villar; and M. E. P. Corona (2024). The role of fire in the germination of invasive plants in Mediterranean environments: A meta-analysis. *Forest Ecology and Management*, 569: 122168.

Zabaleta Mok, H.; S. K. Arndt; and C. R. Nitschke (2012). Modelling the potential impact of climate variability and change on species regeneration potential in the temperate forests of South Eastern Australia. *Global Change Biology*, 18: 1053–1072.

Zvyagintsev, D. G. (Ed.) (1991). *Methods of soil microbiology and biochemistry*. Moscow: Moscow State University Publishing House. 304 p.

تأثير حرائق الغابات في السمية النباتية للتربة في محمية الأرز والشوح، شمال غرب اللاذقية، سورية

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تاريخ الاستلام: 16/ 02/ 2026 **تاريخ القبول:** 8/ 04/ 2026

الملخّص

هدفت هذه الدراسة إلى تحديد درجة السمية النباتية لتربة محمية الأرز والشوح (منطقة صلنفة، اللاذقية، سورية) عقب حريق عام 2020. وقد استُخدمت السمية النباتية كمؤشر حيوي فعّال لتقييم صحة التربة وتعافيها من خلال دراسة النشاط الحيوي في الترب المتأثرة بالحرائق. جُمعت عينات التربة على السفح الشرقي للمحمية بعد ثلاث سنوات من الحريق وعلى عمقين (0−10 سم و10−30 سم). غطت العينات المأخوذة جميع مستويات شدة الحريق (مرتفعة، متوسطة، ومنخفضة)، إضافة إلى أخذ عينات من المواقع غير المحروقة على السفح لاستخدامها كشاهد. أظهرت النتائج وجود سمية نباتية مرتفعة في الترب المعرضة لحرائق مرتفعة الشدة، تجلّت في تثبيط ملحوظ لنمو المجموع الجذري والخضري. حيث انخفض متوسط أطوال المجموع الجذري والخضري بنسبة 40% و52% على التوالي في العينات المحروقة، كما انخفضت الكتلة الحيوية للجذور بنسبة 29% مقارنةً بالشاهد. وقد يُعزى هذا الانخفاض إلى تكوّن مركبات عضوية سامة تعيق استطالة الجذور نتيجة التحلل الحراري الجزئي للمادة العضوية عند درجات حرارة مرتفعة. وعلى النقيض من ذلك، أظهرت الحرائق منخفضة الشدة تأثيراً تحفيزياً لنمو الجذور والمجموع الخضري، ويرجَّح أن ذلك يعود إلى تحرر العناصر الغذائية من الرماد بعد الحريق. كما أظهرت الدراسة عدم وجود تأثير معنوي لعمق التربة في طول الجذور والمجموع الخضري، في حين كان للعمق تأثير معنوي على الكتلة الحيوية للجذور.

الكلمات المفتاحية: حرائق الغابات، السمية النباتية للتربة، المؤشرات الحيوية، محمية الأرز والشوح، شدة الحريق.