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CORRELATION BETWEEN THE PHYSICAL PROPERTIES AND NPK NUTRIENT CONTENT OF ORCHARD SOILS FOR THE SELECTION OF APPROPRIATE SOIL DECONTAMINATION TECHNOLOGIES

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Abstract

The network of underground pipelines used to transport petroleum products may crack and lead to soil contamination. As these pipelines can be located near orchards, this study investigated soils from quince, plum, and pear orchards. The physical properties of the soils were analyzed comparatively, including density, texture and granulometry, capillarity and permeability. Capillarity, permeability and retention capacity were determined for both water and a petroleum product considered a potential soil pollutant. The analysis of physical properties, together with the NPK nutrient content of each soil type, was used to facilitate the selection of appropriate decontamination technologies. Two pollutant removal methods applicable to all three soil types were evaluated: thermal desorption at 400°C and successive extraction using two solvents, petroleum ether and benzene. Nutrient content was determined before and after each decontamination process.

Key words*: decontamination, nutrients, orchard soil, pollutant.*

INTRODUCTION

Soil is a fundamental natural resource that sustains agricultural ecosystems and supports long-term food production. Orchard soils, in particular, require careful and continuous monitoring, as the specific physical properties of the soil, including texture, bulk density, granulometry, capillarity, and permeability, directly influence the growth requirements of fruit tree species such as quince, plum, and pear (Capri et al., 2023; Özdemir et al., 2022). Knowledge of these properties is essential not only for the appropriate selection of fruit tree species, but also for the efficient management of irrigation and fertilization practices. In this context, monitoring the NPK nutrient content of orchard soils plays a central role in achieving sustainable yields, as imbalances in nitrogen, phosphorus, and potassium directly affect tree physiology, flowering, and fruit quality (Sun et al., 2023; Rusu et al., 2025).

Since each fruit tree species has specific growth requirements, knowledge of the physical properties of the soil is essential. Furthermore, determining the nutrient content of orchard soils allows for the appropriate application of fertilizers. Recent studies show that orchard soils require constant and careful monitoring, with the recommendation including the use of sewage sludge with high nutrient content (Iorga et al., 2025) and fertilization with compost (Butcaru et al., 2024). Other authors conducted a comparative study between a conventional system based on herbicide use and a conservation system based on cover crops, evaluating nutrient content in a plum orchard (Rusu et al., 2025). The use of biofertilizers as alternatives to chemical fertilizers has also been investigated. Studies were conducted in an apple orchard over a period of five years (Ferreira et al., 2025) and in a pear orchard over a period of two years (Li et al., 2025). The combination of cover crops with legumes planted in orchards has been shown to improve the nutrient cycle (Raimundo et al., 2025). Other studies on nutrient uptake were carried out in cherry orchards (Karampatzakis et al., 2025) and pear orchards (Liu et al., 2025), with particular emphasis on tree age. Recent studies also highlight the importance of factors such as temperature, irrigation water, the use of biostimulants, and weed presence for ensuring good crop production in orchards (Lisek, 2023; Cara, 2025). The application of the electrokinetic decontamination method, with different types of electrodes, on agricultural soil led to different changes in NPK nutrients (Popa, 2025).

Nitrogen is responsible for leaf growth; its deficiency causes yellowing, while an excess can prolong the vegetation period. Phosphorus is important for the functioning of the immune system and stimulates the flowering process. Potassium is converted, through chemical reactions, into potassium hydroxide, which stores nutrients required by the plant. When potassium is deficient, the intensity of photosynthesis decreases.

Beyond agronomic challenges, orchard soils located in proximity to major petroleum product transport infrastructure face an additional risk: accidental contamination with hydrocarbons resulting from pipeline failures or leaks (Franchi et al., 2022; Adeniran et al., 2023). Such contamination events pose a serious threat to soil fertility and long-term agricultural productivity, as petroleum hydrocarbons alter the physical structure of the soil, disrupt nutrient availability, and suppress microbial activity (Ambaye et al., 2022; Ossai et al., 2020). The selection of an appropriate decontamination strategy is therefore critical, as it must balance the effective removal of the pollutant with the preservation of the soil's agronomic potential. Among the available remediation technologies, thermal desorption and successive solvent extraction have been evaluated as viable approaches for hydrocarbon-contaminated agricultural soils (O'Brien et al., 2024; Caetano et al., 2024). However, the impact of these methods on soil nutrient content, particularly NPK levels, remains an aspect that requires further investigation, especially in the context of orchard soils.

MATERIALS AND METHODS

Major pipelines can be located very close to orchards; therefore, this study focuses on two neighboring counties in Romania where such risks may occur: Prahova and Dambovita (Figure 1). Although the main pipeline network in Romania is continuously monitored, rapid action is required if soil contamination with petroleum hydrocarbons occurs.

Soil samples used in this study were collected from quince and pear orchards in Dambovita County and from plum orchards in Prahova County. This study compares two methods for the decontamination of soils contaminated with hydrocarbons: successive extraction with solvents and thermal desorption.

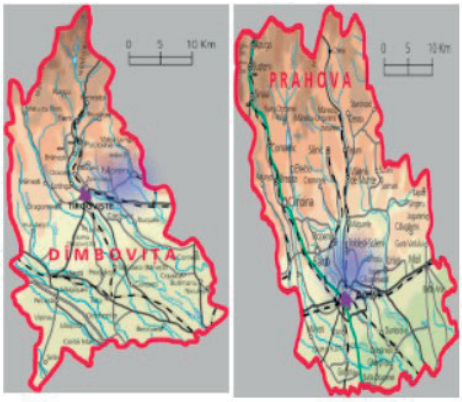


Figure 1. The orchard areas

Soil characterization involved determining the physical properties of the three samples. Additionally, for pollution control conducted in the laboratory, diesel oil was characterized by its density and viscosity. These properties of diesel oil help to understand how it penetrates the soil structure. The concentration of pollutants in soil was 7% by mass, a percentage deliberately chosen as it falls within the minor pollution range. All methods used to determine the physical properties of the analysed soil samples have been described in previous works (Popa, 2023; 2024).

Capillarity, defined as the maximum height a liquid can reach in the soil within one hour, represented by the ascent phenomenon, was established. Permeability, the property that ensures the penetration of liquid from top to the bottom of the soil, was calculated as the average permeability over one hour of exposure to the soil. This property depends on the free spaces between the solid aggregates of the soil, as well as the physicochemical interactions formed with the fluid molecules passing through the soil.

The liquid retention capacity of the soil was also determined and expressed in liters of liquid per $1m^3$ of dry soil. Both permeability and retention capacity were tested for water and diesel oil. Permeability could be determined for only a single measurement for diesel oil, at 15 minutes, due to a high pollutant consumption for the soil in the quince orchard. Granulometry was determined using the sieving method with four

different sieve diameters (1.6 mm, 1 mm, 0.5 mm and 0.25 mm).

Based on the laboratory determined grain size, soil texture was established, allowing for verification of differences between the two regions from which the soil originated. All physical properties were determined on dry soil samples (oven-dried at 105°C, for one hour), thus establishing the initial moisture content of the samples (% mass).

The NPK nutrient content was determined qualitatively. In orchards, monitoring nutrient content is essential to achieving good yields. The reagents used in the Hanna test kit (Popa, 2023) are pre-measured solutions specially formulated for colorimetric and turbidimetric reactions, which enable the rapid and accurate determination of essential NPK nutrients. The kit defines the following ranges: trace (0-5 ppm), low (5-15 ppm), medium (15-30 ppm), high (30-50 ppm).

Dry soils, pre-heated for one hour at 105°C, were contaminated with 7% diesel oil and immediately subjected to thermal decontamination. The process was carried out at 400°C, enabling both pollutant recovery and water removal at elevated temperatures.

The apparatus has been described in the literature (Popa, 2023). Decontamination by successive solvents extraction was performed using two solvents, petroleum ether and benzene, using a Soxhlet apparatus as described in the literature (Popa, 2024).

RESULTS AND DISCUSSIONS

Characterization of clean soils

The analyzed clean soils were characterised by their physical properties (Table 1), and nutrient values were estimated at the upper limit of the recommended range provided by the analysis kit.

Table 1. Characterization of clean orchard soil samples

Property	Type of orchard soil		
	Quince	Plum	Pear
Max. capillarity to water (cm)	4.6	3.5	3.6
Max. capillarity to diesel oil (cm)	8.5	7.3	7.4
Permeability to water (cm^3/h)	8400	411.4	596.28
Water retention capacity (kg water/m^3 soil)	170.1	384.6	324.2
Diesel oil retention capacity (kg diesel oil/m^3 soil)	29	64	42
Max nutrients content (mg/kg soil)			
N	5	30	30
P	30	15	30
K	50	15	15
pH	6.5	6.5	5.5
Moisture (% mass)	18	20.1	18.3
Granulometry (g)			
Sieve diameter			
1.6 mm	58	58	58.6
1 mm	14.9	16.2	16.5
0.5 mm	18	13.6	18.9
0.25 mm	8.9	5.8	5.5
losses on the sieve	0.2	6.4	0.5
Textural class	sandy	sandy loam	sandy
Conductivity (µS/cm)	120	150	134
Apparent density (g/cm^3)	1.36	1.58	1.38
Real density (g/cm^3)	2.74	2.60	2.65
Porosity (%)	50.3	39.2	47.9

The physical properties of the three analyzed soils reveal significant differences related to their textural class and geographical origin. The quince orchard soil, classified as sandy, exhibited the highest capillarity to diesel oil (8.5 cm) and the highest permeability to water (8400 cm^3/h), indicating a very open pore structure that facilitates rapid fluid movement. Consequently, its water retention capacity was the lowest (170.1 kg/m^3), which suggests that this soil type is the most vulnerable to deep pollutant infiltration in the event of a petroleum spill. In contrast, the plum orchard soil, classified as sandy loam, displayed the highest water retention capacity (384.6 kg/m^3) and the lowest permeability, reflecting a denser, more cohesive structure with a lower porosity of 39.2%. The pear orchard soil presented intermediate values between the two, with a sandy texture and a porosity of 47.9%. Regarding nutrient content, notable differences were observed among the three soils: the quince soil was characterized by low nitrogen (5 mg/kg) and high potassium (50 mg/kg), the plum soil showed a balanced but moderate NPK distribution, while the pear soil presented elevated nitrogen and phosphorus content (30 mg/kg each). These differences reflect the distinct fertilization histories of each privately owned orchard and underline the importance of site-specific nutrient monitoring.

Characterization of diesel oil

To illustrate how the pollutant penetrates the soil structure through the soil's capillary and permeability properties, as shown in Table 1, it was necessary to characterize the pollutant in terms of density and viscosity. These are key properties for the pollutant - diesel oil - and are presented in Table 2.

The density of diesel oil (850.5 kg/m^3 at 20°C) is significantly lower than the real density of all three soil types (2.60-2.74 g/cm^3), which means that diesel tends to remain in the upper soil layers and within the pore spaces rather than sinking rapidly to deeper horizons.

However, its low kinematic viscosity ($3.57 \times 10^{-4} m^2/s$ at 40°C) facilitates mobility through the soil matrix, particularly in sandy soils with high permeability such as the quince and pear orchard soils. These properties are relevant for understanding the capillarity and permeability results observed in Table 1, where diesel oil consistently reached higher capillary heights than water, due to its lower surface tension and different wetting characteristics relative to the soil mineral surfaces.

Table 2. The physical properties of diesel oil

Physical properties	Value
Density (kg/m^3) at 20°C	850.5
Kinematic viscosity·10^4 (m^2/s) at 40°C	3.57

Thermal desorption for soil decontamination

The extent of decontamination achieved by thermal desorption as summarized (Table 3). Following thermal decontamination, the nutrient content of the soils was restored (Table 4).

Table 3. The degrees of decontamination established after thermal desorption

Measured	Type of orchard soil		
	Quince	Plum	Pear
Diesel oil volume (ml)	4.76	3.64	3.59
Volume of water desorbed (ml)	3.7	5.25	2
Volume of diesel oil desorbed (ml)	3.1	3.25	3
Degree of decontamination achieved (%)	83.8	89.3	83.6

Table 4. Nutrient content after desorption decontamination

Nutrient	Type of orchard soil (mg/kg)		
	Quince	Plum	Pear
N	5	5	30
P	50	15	15
K	30	5	15

Successive solvents extraction for soil decontamination

Clean samples were decontaminated to quantify the organic material extracted according to soil structure (Table 5).

Table 5. Extraction results for the clean sample

Measured	Type of orchard soil		
	Quince	Plum	Pear
Organic material with petroleum ether (%)	0.08	0.41	0.55
Organic material with benzene (%)	0.16	0.27	0.39
Total organic material extracted (%)	0.24	0.68	0.94

Soil samples contaminated in labor with 7% diesel oil were subjected to successive solvents extraction. The results obtained for the clean sample were used as a reference. The final results establishing the degree of decontamination are presented (Table 6).
After solvents extraction, the nutrient content of the soils was re-established (Table 7).

Table 6. The degrees of decontamination established after extraction

Measured	Type of orchard soil with 7% diesel oil		
	Quince	Plum	Pear
Diesel oil with petroleum ether (%)	46.18	49.8	49.7
Diesel oil with benzene (%)	11.18	23.9	40.8
Degree of decontamination achieved, (%)	57.36	73.7	90.5

After the application of the decontamination methods, the soil pH values increased, except for the plum orchard soil, which showed a lower pH value after extraction (Table 8).
At 400°C, the acidic organic fractions in the soil and in the pollutant suffer degradation and volatilization, leading to an increase in basic mineral compounds and, consequently, to a rise in pH.

Table 7. Nutrient content after extraction decontamination

Nutrient	Type of orchard soil, (mg/kg)		
	Quince	Plum	Pear
N	50	50	30
P	50	15	30
K	30	30	30

Changes in soil composition and buffering capacity can cause the pH to shift toward more alkaline values during successive solvent extraction.

Table 8. Variation of soils pH

pH	Type of orchard soil		
	Quince	Plum	Pear
pH for clean soil	6.6	6.5	5.5
pH of soil after desorption	8.5	5.5	6
pH of soil after extraction	7.5	8	7

The application of decontamination methods highlights changes in nutrients content (Figure 2).

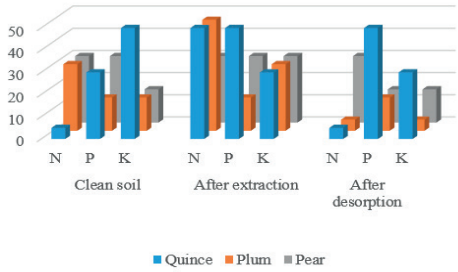


Figure 2. Variation of nutrients content

It should be noted that the orchards from which the samples were collected are privately owned and relatively small in size, each having received organic amendments. The fertilizers applied were not consistently monitored; therefore, different nutrient contents were observed in the clean soil samples (Table 1). The orchards are located in areas vulnerable to pollution due to accidental leaks from main petroleum product transport pipelines.

Thermal desorption at 400°C proved effective for all three soil types, achieving decontamination degrees ranging from 83.6% (pear orchard soil) to 89.3% (plum orchard soil). The plum orchard soil, which had the highest diesel oil retention capacity (64 kg/m³), also yielded the largest volume of desorbed water (5.25 ml), suggesting that its higher moisture content and denser structure required more energy for complete pollutant volatilization. The quince orchard soil, despite its high permeability, achieved a decontamination efficiency of 83.8%, likely due to the high initial pollutant mobility within its open pore structure. Overall, the results confirm that thermal desorption at 400°C is a reliable method for recovering petroleum hydrocarbons from all three soil types, with recovery rates consistently above 83%. The present study was based on the assumption that variations in nutrient content (NPK) in orchard soils may influence the selection of an appropriate decontamination technology. At the same time, soil pH was found to play an important role.

Following thermal desorption, notable changes in NPK nutrient content were recorded compared to the initial clean soil values (Table 1). In the quince orchard soil, phosphorus increased significantly (from 30 to 50 mg/kg), while nitrogen remained stable (5 mg/kg) and potassium decreased (from 50 to 30 mg/kg). In the plum orchard soil, all three nutrients decreased markedly, with nitrogen dropping from 30 to 5 mg/kg and potassium from 15 to 5 mg/kg, suggesting that the high treatment temperature caused volatilization or transformation of nitrogen compounds and leaching-like redistribution of potassium. The pear orchard soil showed an increase in nitrogen (from 30 to 30 mg/kg - unchanged) and stable phosphorus and potassium values. These results indicate that thermal desorption, while highly effective for pollutant removal, exerts a heterogeneous influence on nutrient content depending on the soil's initial composition and texture.

A comparison of the two decontamination approaches reveals that successive solvents extraction exerts a relatively mild impact on soil structure and nutrient content, while inducing minimal changes in pH. This method is predominantly linked to the mobilization of nutrients associated with organic matter. Conversely, desorption primarily interacts with the mineral fraction of contaminated soils, leading to a more pronounced increase in pH. When performed at 400 °C, desorption facilitates the determination of available nutrient content through mineralization. An advantage of the desorption method lies in its ability to recover and reuse the pollutant in relatively high proportions (over 83%), but the application of desorption can affect long-term fertility. For orchard soils, permanent irrigation is necessary (permeability is high), as is the controlled use of organic amendments, possibly alternating them, and nutrient supplements.

Successive solvent extraction with petroleum ether and benzene yielded decontamination efficiencies ranging from 57.36% (quince orchard soil) to 90.5% (pear orchard soil). The pear orchard soil achieved the highest removal efficiency, with both solvents contributing substantially (49.7% with petroleum ether and 40.8% with benzene). In contrast, the quince orchard soil showed the lowest overall efficiency despite its high permeability, which may be attributed to strong adsorption interactions between the diesel oil and the sandy soil matrix at the concentration used. The plum orchard soil achieved an intermediate efficiency of 73.7%. Notably, petroleum ether consistently outperformed benzene in the first extraction step across all soil types, suggesting that the lighter, non-polar diesel oil fractions are more readily mobilized in the initial extraction phase, with benzene recovering the heavier residual fractions in the second step. Successive solvent extraction had a generally positive or neutral effect on nutrient content compared to the initial clean soil values. The quince orchard soil showed significant increases in nitrogen (from 5 to 50 mg/kg) and maintained its phosphorus level (50 mg/kg), while potassium remained stable (30 mg/kg). The plum orchard soil similarly showed a marked increase in nitrogen (from 30 to 50 mg/kg) and potassium (from 15 to 30 mg/kg), with phosphorus unchanged (15 mg/kg). The pear orchard soil maintained stable nitrogen and phosphorus levels (30 mg/kg each) and showed an increase in potassium (from 15 to 30 mg/kg). These results suggest that solvent extraction, unlike thermal desorption, does not destroy nutrient compounds and may even

mobilize organically bound nutrients, making it a more agronomically favorable option with respect to post-treatment soil fertility. Changes in nutrient content before and after remediation were also observed in agricultural soil when the electrokinetic remediation method was used (Popa, 2025).

The results obtained are similar to the literature on the properties of orchard soils (Tkaczyk et al., 2018).

The application of both decontamination methods induced measurable changes in soil pH. Following thermal desorption, the pH increased substantially in the quince orchard soil (from 6.6 to 8.5) and moderately in the pear orchard soil (from 5.5 to 6.0), while the plum orchard soil experienced a decrease (from 6.5 to 5.5). The pronounced alkalinization observed in the quince soil after desorption can be attributed to the thermal degradation and volatilization of acidic organic fractions, combined with the formation of basic mineral compounds at 400°C. After solvent extraction, pH values generally shifted toward slightly alkaline conditions in the quince (7.5) and plum (8.0) soils, while the pear soil showed a moderate increase (from 5.5 to 7.0). The exception was the plum soil after thermal desorption, which showed a slight acidification, possibly linked to the selective volatilization of alkaline compounds or the release of acidic intermediates during the process. Overall, both methods tend to increase soil pH, which should be considered when planning post-treatment agronomic management, particularly for species sensitive to alkaline conditions.

CONCLUSIONS

The selection of appropriate technologies for the decontamination of hydrocarbon-polluted soils represents a challenging task. Methods that allow the recovery of the pollutant to the greatest possible extent are generally preferred. In the case of the orchard soils investigated in this study, slight differences in the determined decontamination efficiencies were observed.

Both thermal desorption at 400°C and successive solvent extraction with petroleum ether and benzene proved effective for the removal of diesel oil from all three soil types. Thermal desorption achieved decontamination efficiencies above 83% for all samples, while solvent extraction yielded efficiencies ranging from 57.36% to 90.5%, with the highest performance recorded for the pear orchard soil. With respect to nutrient content, successive solvent extraction demonstrated a milder and generally more favorable impact on NPK levels, in some cases even increasing the available nutrient content through the mobilization of organically bound compounds. Thermal desorption, while highly efficient for pollutant recovery, produced more variable and in some cases more pronounced changes in nutrient content, particularly for nitrogen and potassium, and led to a significant increase in soil pH, factors that may affect long-term soil fertility.

The results confirm that the selection of an appropriate decontamination technology for petroleum-contaminated orchard soils cannot be based solely on removal efficiency, but must also account for the post-treatment agronomic status of the soil, including nutrient availability and pH. For this study, a comparison of the decontamination methods used leads to the conclusion that, although the degree of decontamination achieved by the successive solvent extraction method is lower than that achieved by the thermal desorption method, the change in nutrient content is more favorable for extraction.

The use of soil amendments must be carefully monitored so that, in the event of accidental pollution with hydrocarbons, this factor is taken into account when selecting a decontamination method.

Future research should explore additional decontamination methods, such as soil washing with environmentally friendly surfactants and electrokinetic decontamination, and assess their impact on a broader range of soil fertility indicators, in order to support the development of integrated and sustainable remediation strategies for orchard soils affected by accidental hydrocarbon contamination.

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