THE REHABILITATION OF FOREST SOILS FROM GIURGIU COUNTY POLLUTED WITH PETROLEUM

REABILITAREA UNOR SOLURI FORESTIERE DIN JUDETUL GIURGIU POLUATE CU PETROL

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Abstract. *Accidental petroleum hydrocarbon leakages or from other products used in the petroleum extraction process represent an important pollution for both the soil and the environment. The rehabilitation of fields used temporary for the extraction of petroleum requires a series of measures and works based on the soil's physical-chemical properties. The present paper presents the state of soils from three forest field surfaces located in Giurgiu County where probes were installed. Currently, these fields are unrigged. The article then focuses on the improvement and silvotechnical measures and works necessary for the restoration of fields back to the forest sector to which they belong. In most situations, these fields are deranged (excavated, levelled and battered), polluted with hydrocarbons and saline water or with other products used in extraction processes. The restitution of fields from drilling areas back to the forestry circuit implies the application of specific technologies for preparing the field and for improving the soil. This is complemented by the application of special afforestation technologies based on the specific characteristics of both field and soil. In the case of soils weakly-moderately polluted with petroleum hydrocarbons, special rehabilitation or bio-restoration works are necessary in order to obtain their afforestation. These works might consist in mineral fertilisation, organic fertilisation, amendments or scarification.*
Key words: pollution, petroleum hydrocarbons, soil rehabilitation, afforestation

Rezumat. *Scurgerile accidentale de hidrocarburi petroliere sau alte produse utilizate în procesul de extracție al petrolului reprezintă o importantă formă de poluare a solului şi a mediului înconjurător. Reabilitarea terenurilor utilizate temporar pentru activitatea de extracție a petrolului, impune o serie de măsuri şi lucrări în funcție de caracteristicile fizico-chimice ale solului. În lucrare este prezentată starea solului în trei suprafețe de terenuri silvice din județul Giurgiu, pe care au fost instalate sonde, în present acestea fiind dezafectate, precum şi măsurile şi lucrările ameliorative şi silvotehnice necesare pentru redarea terenurilor respective sectorului silvic, căruia îi aparțin. În cele mai multe situații, solurile din terenurile pe care au fost amplasate sondele au fost deranjate (excavate, nivelate, tasate), poluate cu hidrocarburi, apă salină, bentonite şi alte produse utilizate în procesul de extracție. Redarea terenurilor din careul sondelor în circuitul silvic impune aplicarea unor tehnologii specifice de pregătire a terenului şi de ameliorare a solului şi aplicarea unor tehnologii speciale de împădurire. În raport cu*

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caracteristicile terenului şi solului. În cazul solurilor slab-moderat poluate cu hidrocarburi petroliere, pentru a se creea condiții minime în vederea împăduririi sunt necesare lucrări speciale de reabilitare sau bioremediere constând în fertilizare minerală sau fertilizare ameliorativă organică, amendamentare, scarificare s.a.

Cuvinte cheie: poluare, hidrocarburi petroliere, reabilitarea solului, împădurire

INTRODUCTION

Fields from the national forest funds on which drills were placed for the extraction of petroleum require a series of soil amelioration and remediation measures after they were closed (abandoned) and unrigged. Accidental petroleum hydrocarbons leakages or form other products used in the petroleum extraction process represent an important pollution of both soil and environment. The negative effects of these hydrocarbons consist in obstructing soil water circulation and the exchange of gases due to their impermeable layer formed from their compounds. As a result, the root suffocation phenomenon occurs, complemented by reduction processes (Potra, 2011). As the internal soil environment becomes anaerobe, the number and activity of bacteria and microorganism is steadily reduced. The existence of petroleum hydrocarbons in soils affects seed germination, plant growth (forest seedlings) and obstructs their normal development during the vegetation season. Hydrocarbons can penetrate seeds and kill the embryo or they can affect germination by reducing the water flux towards seeds or by decreasing the oxygen necessary for germination (Potra, 2011).

The rehabilitation of soils polluted with petroleum can be obtained through different bio remedy or bio stimulation methods in which additional nutrients (nitrogen, phosphorus or other organic or mineral fertilisers) are used for degrading petroleum hydrocarbons. Bio remedy was successfully used in controlling hydrocarbon contaminations. The bio remedy techniques include a number of systems or processes that use microorganisms in order to treat soils and phreatic water in order to degrade or decompose petroleum hydrocarbons (Potra *et al.*, 2012).

The bio remedy of soils contaminated with petroleum is an efficient, sure, versatile and economic technique that is friendly with the environment and can be used complementary with physical-chemical treatments. The bio remedy technology (ICPA, 2017) proposes the following solutions: scarification for stimulating the aero hydric regime; organic ameliorative fertilization; ameliorative works for soils that are weakly-moderately polluted (removing petrol excess, amendments, mineral fertilization with NPK (bio stimulation) with an increase of nitrogen percentage for reducing the C:N proportion); applying absorbents (at the soil's surface for petroleum absorption and retention, being a good resource in nutritive and water elements).

MATERIAL AND METHOD

Three fields were taken into account for this study. With a surface between 1386 – 1750 m^2, these fields had drills for the extraction of petroleum but are now disaffected (abandoned). The fields are located in the national forest fund, in the Videle area, managed by Ghimpati Forest District (U.P. II Milcovăt, u.a. 24M3, 25M3, 25A%, 39M1, 39A%, DS Giurgiu (fig. 1; ICAS, 2014). From a geographic point of view, the U.P.II Milcovăț forests are situated in the West part of Giurgiu County, namely in Câlniştei Plain. From a phyto-climatic point of view, the analysed territory is situated in the forest plain level (100%) which is represented by Hungarian oak and Turkey oak mixtures.

In order to emphasize the soils' characteristics, one main soil profile was realized on each surface (drill's perimeter) and in the control profile, at a distance of 25-30 meters. A soil profile (named witness profile) was also realized in the forest bordering the drill's perimeter. The profiles were realized at a depth of approximately 60-65 de cm (the basic rock being situated under this depth). The samples were gathered from 20-25 cm layers in order to ensure a better appreciation of the soil's characteristics and implicitly, of the changes caused on each profile. This method was also applied in places where the horizon's/layer's depth exceed 25 cm. In this way, we were able to observe if the affected soil has suffered or not changes in composition and structure. Three soil samples were gathered for each profile.

The soil samples gathered from the three main soil profiles from near the drills or from neighbouring fields were analysed from a physical-chemical point of view in the Ecopedology Analysis Laboratories from INCDS "Marin Dracea" (from Voluntari and Brasov). The following elements were determined: pH, humus content, carbonates, nitrogen, mobile phosphorus, mobile potassium, soluble salts, and granulometric fractions (Dincă *et al.,* 2012; Crişan *et al.*, 2020; Edu *et. al.,* 2013). The other physical characteristics (structure, compactness, colour) were determined organoleptically.

Furthermore, different soil samples were gathered from depths up to 30 cm and from 31-60 cm in order to establish the content of hydrocarbons from petroleum. The samples were analysed in the laboratory from the Technological Design and Research Institute (ICPT), Campina, where the content of petroleum hydrocarbons (TPH – **total petroleum hydrocarbons**) was determined through FT-IR spectrometry. The TPH values, expressed in mg/kg, were compared with reference values (established by OM 756/1997) regarding the total content of petroleum hydrocarbons in order to establish if the soil's petroleum hydrocarbon content is situated within the admissible limits for sensible usages (including forests) and if it allows the reinstallation of forest vegetation.

RESULTS AND DISCUSSIONS

The studied fields (drill perimeter and access road) and especially their soils were affected by petroleum extraction activities as well as by auxiliary services (transport, heavy machines etc.) used in draining and compacting the soil. This is complemented by an accidental pollution with petroleum residues and other substances used or resulted from the petroleum extraction process (salted water, bentonit, extraction mud, etc).

Different changes in soil characteristics have resulted from petroleum extraction activities or from abandoning the drills. These were caused by: field levelling; drill excavation and installation (with the effect of uncovering the soil's fertile layer); the presence of heavy machines (leading to a strong soil compaction, especially on the access road); the accidental discharge / leaking of petroleum, salted water or extraction mud (bentonit) which leads to the soil's pollution, saturation or argillic alteration; the polluted layer's uncovering (after the drill's abandonment) and the field's covering (soil and stone mixture) originating from other usage areas than forests which have led to the mixture of soil horizons/layers.

Fig. 1 The location of fields

The following characteristics were emphasized based on field observations and the results of the soil's physical-chemical analyses:

-the soil layer is superficial (60 – 62 cm), being represented by a soil-stone mixture, with the soil's predominance, resulted from uncovering (or excavating the polluted soil layer) and covering with a soil (mixture) originating from another area;

-the texture is loam-clay-powdery, having a relatively variable clay, dust and sand content from one profile to another and even for the same profile (tab. 1); clay content is relatively high on the surface (41.4 – 43.4% in the soil's first layer) and increases or sometimes decreases in the following layers, ranging between 38.62 and 49.87%. This fact emphasized the different nature of soil layers mixed with clay with which the field was covered; argilisation is also caused by the usage of bentonit in the petroleum extraction process;

-the content of nutritive and mineral elements varies from one profile to the other and from one horizon to another, having sometimes higher values in intermediary of inferior horizons. This aspect emphasized the characteristics of a soil with mixed horizons; as such, the humus content is very low in all profiles, varying between 1.2 – 3.4% at the surface and between 1.35 and 2.69% in depth; the total nitrogen content is also variable, being in general small or very small (0.084-0.168 mg/100 g sol); the phosphorus content varies from 6.86 (high) to 0.31 mg/100g sol (extremely low) in the superior horizon and between 1.86 (average) and 6.41 mg/100 g sol (high) in the inferior horizon; the potassium content varies from 1.80 (extremely low) to 4.34 mg/100 g soil (low) at the surface and from 3.71 (very low) to 4.61 mg/100 g sol (low) in depth (tab. 2);

Table 1

Results of the soil's physical analyses

Drill name	Surface (mp)	Field location, county	Soil Profile	Soil profile in the basis profiles (cm)	Sand	Dust	Clay
2371 Videle Est	1.750	Giurgiu	P1	0-17	9.822	46.747	43.431
				18-40	3.232	48.150	48.618
				41-62	16.545	44.832	38.623
2431 Videle Est	1.386	Giurgiu	P1	0-19	4.740	53.353	41.907
				20-45	1.843	50.109	48.048
				46-60	1.592	49.546	48.862
2463 Videle Est	1.729	Giurgiu	P1	0-19	5.341	53.519	41.140
				20-41	5.252	57.771	36.978
				42-60	2.664	47.466	49.869

Table 2

Results of the soil's chemical analyses

Drill name	Depth cm	pH	Ht %	Nt %	Pm mg/ 100g	Km mg/ 100g	Soluble salts mg/100g	V %
2371	0-17	8.43	1.20	0.084	0.31	1.80	47.54	
	18-40	7.04	1.55	0.084	1.45	2.88	32.17	
	41-62	7.75	2.69	0.168	3.19	3.71	48.08	
2431	0-19	5.96	3.40	0.168	3.99	3.84		70.80
	20-45	5.73	1.97	0.112	1.97	3.68		73.54
	46-60	6.14	1.67	0.084	1.86	3.92		76.89
2463	0-19	6.12	2.15	0.084	6.86	4.34		68.97
	20-41	7.29	2.84	0.140	4.94	3.37	41.65	
	42-60	5.62	1.35	0.112	6.41	4.61		68.08

-pH is also variable per profile (with a different tendency) and from one profile to another, having values between 5.96 (moderately acid), and 8.43 (moderately alkaline) in the superior horizon and between 5.62 (moderately acid) and 7.75 (weakly alkaline) in the inferior horizon;

-soluble salts are missing in a soil profile (drill 2431) and is present only in the intermediary horizon or on the entire profile in concentrations of up to 48,08 mg/100g soil. These values are considered as admissible for forest vegetation (<100 mg/100 g sol).

The analysed soils are in general weakly polluted with petroleum hydrocarbons, registering TPH values <85 mg/kg (tab. 3), considered admissible values for forest vegetation. A value of 150 de mg/kg was determined for 2431 Videle Est drill at the depth of 30-60 cm. This value exceeds the admissible threshold of 100-200 mg/kg (OM 756/1997), being part of the category of alert values for sensible usages (including forests). This presence determines changes in the soils' physical-chemical properties by decreasing the mineral substances complex (N, P, K) and the usage of carbon sources by plants as well as by blocking infiltration canals for superficial waters. As a consequence, the profile's inferior part of this soil presents an average C:H ration which determines a weakly-moderately degree of hydrocarbon pollution.

Table 3

Results of the soil's TPH analysis

Drill name	Surface (mp)	Location (Production area, County)	Soil profile	TPH (mg/kg) in depth (cm)	
				0-30	30-60
2371	1.750	Asset Moesia Bolintin Vale, Giurgiu	P1	<85	<85
2431	1.386		P1	<85	150
2463	1.729		P1	<85	<85

Based on the obtained results and the realized observations, the soils from the drill's perimeter were situated in the following soil class: **Antrisols (ANT)** (Undeveloped soils, truncated or rutted), soil type: **techno-soil (TT)** – resulted from human transformations, soil subtype: **covered (TTct),** sometimes weakly-moderately polluted with petroleum.

Soils from the forest fund that boarders the drill perimeter are situated in the **LUVISOIL class (LUV)**, **preluvosoil and luvosol** soil type, **vertic** subtype. They offer good conditions for average productivity Hungarian oak and Turkey oak stands (Chisăliță *et. al.*, 2015). Honey locust can also be observed in their composition, being a species that vegetates and resists well with other forest species on soils with a loamy-clay structure, compact or even strongly compact (Constandache *et al.*, 2016; Dincă *et al.*, 2018; Murariu *et al.*, 2018; Cântar *et al.*, 2018; Blaga *et al*, 2019).

The analysis of factors that determine the soil's fertility, namely edaphic factors (soil components, the content of nutritive and mineral elements, pH etc.) was realized in accordance with current technical norms (MMAP, 2000) and has resulted in the following stational framing of the analysed fields: Stational Group (G.S. - 129) – *fields with deranged or rutted soils, with a soil and stone mixture and the predominance of soils in the first 30 - 50 cm.*

A series of works for the preparation of fields and soils as well as silvotechnical works (afforestation) are necessary for the reintroduction of the fields in the forest fund.

Preparing the field and soil. Works for field preparation and soil preparation / amelioration are necessary for ensuring the minimum conditions for the installation of forest cultures (INCDS, 2020). These are different and based on the soil's characteristics.

The SAD technology (scarification, ploughing, 2 discs) is recommended for the two surfaces (drills) where the soils is not so affected by pollution and where the TPH values are situated within the admissible limits. Another option for soil improvement consists in covering with fertile soil of minimum 30-40 cm (which is very hard to achieve).

The scarification of strongly compacted soils with a low aeration porosity is realized in order to improve the soil's aero-hydric conditions. Scarification will be realized at the 60 cm depth, with a distance of 1 m between active organs. The optimum execution moment is when the soil has a humidity of 60-80% from the active humidity interval.

Amendments (gips or phpsphogypsum) are recommended cases where the soil is alkaline (pH >8.41). The amendments must be applied and incorporated in the soil together with scarification.

The bio-remedy technologies of soils polluted with petroleum hydrocarbons (ICPA, 2017) recommend the fertilisation with 150 t/ha of fermented or composted manure for fields affected by petroleum pollution (with TPH >85 of the admissible values). They must be applied evenly on the polluted field and must be followed by scarification. Manure ensures a better soil aeration as well as a higher diversity of microorganisms. These microorganisms participate in the bio-remedy process, break the petroleum cover, retain hydrocarbons at the soil's surface (where the area is more aerated and where most of them are lost through volatilization), ensure a large array of macro and micro nutritive elements accessible for plants, stimulate soil water retention and soil structuring and improve all soil physical parameters (Dumitru *et al.*, 2016).

Mineral fertilization is necessary for oil pollution that causes a soil nitrogen shortage situated in abnormal ratios with the organic carbon brought by hydrocarbons (C:N ratio too high). Nitrogen and phosphorus are recommended to be applied in order to obtain the C/N/P de 300/10/1 - 100/10/1 ratio. The dosages should not exceed 200 kg/ha N for one application in order to avoid toxicity for microorganisms and the unnecessary loss through washing. Dosages of 200 kg/ha N, 100 kg/ha P and 100 kg/ha K were applied for the improvement of agricultural fields polluted with petroleum in order to achieve and maintain the equilibrium of soil nutritive elements and for creating rapid multiplication conditions for their microorganisms (ICPA, 2016).

Afforestation. The following recommendations (INCDS, 2020) should be applied for afforestation and in accordance with current Technical Norms (MMAP, 2000):

- Composition and planting scheme: 25 Pi.n (Ce) 50 Ul.T (Mj, Vi.t) 25 arb (Pd, Sâ, Po), wheree: Pi.n – black pine; Ce – Hungarian oak; Ul.T –Turkestan elm; Mj – manna; Vi.t – Turkish cherry; arb - shrubs, Pd – hawthorn; Sâ - dogwood; Po – blackthorn;
- Afforestation technique: planting, in common holes with seedlings in bags (Pp) for pine and Hungarian oak and with common seedlings for the other species.
- Plantation scheme: 2 x 1 m; culture density: 5000 samples/ha; the mixture will be realizes in rows R1 = Pi.n (Ce) + arb; R2 = Ul.T (Mj, Vi.t);
- Addition: 30%, from which 20% in IInd year and 10 % in III^{d} year;
- Culture maintenance– 13 times in 5 years (until a definitive success), from which: revisions – 3 (1st, 2nd, 3^{d} years); mobilisations (around seedlings) – 7 times in 5 years (2+2+1+1+1); weding – 3 (one in the 3^{d} year, one in the 4th year and one in the 5th year).

CONCLUSIONS

The physical processes caused by petroleum extraction activities consist in deranging the soil's fertile layer within exploitation parks (excavated surfaces, transport network, electric network, pipes under pressure and buried or soil surface cables etc.). They all cause soil compacting, the apparition of changes in the field's configuration and finally, reducing agricultural or silvical productive surfaces. Furthermore, they were accompanied by hydrocarbons pollution, saline water, bentonit and other products used in the extraction process.

Mechanical methods were applied in order to rehabilitate the soils from the studied areas that were polluted with petroleum. They have involved the uncovering of the polluted soil and adding a soil originating from other sources.

Overall, the soils from the drill perimeter are blunted, compact and deranged soils, represented by a mixture of soil with clay. They have a reduced content of nutritive and mineral elements and are weakly-moderately polluted with petroleum hydrocarbons which leads to changes in the soil's structure and in the activity of pedogenetic processes.

Specific technologies must be applied in order to reintroduce these fields in the silvicultural circuit. They include specific technologies for preparing the field and improving the soil as well as special afforestation technologies adapted to degraded lands (deranged, excavated).

Special rehabilitation or bio-remedy works must be applied in the case of soils weakly-moderately polluted with petroleum hydrocarbons in order to ensure minimum conditions for their afforestation. These actions consist in mineral or organic ameliorative fertilisation, amendments, scarification etc.

Acknowledgments*: The data were collected and processed between October 2019 - April 2020, within the elaboration of Pedostational Studies on the state of forest lands occupied by abandoned objectives (oil well) to be reintroduced in the forest area, within the service contract no. 99007515/2019 for OMV - Petrom.*

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