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Dedicated to Professor Costel Sârbu on the Occasion of His 65th Anniversary

ALGORITHM FOR ASSESING SOIL REHABILITATION OF STERILE DUMPS

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ABSTRACT. Ileana Veche is the most representative waste rock (sterile) dump formed by the coal mining activities in Lupeni (Petroşani Basin). We developed an algorithm based on the computational engineering concepts in order to establish the connection between the waste rock soil particles composition and the dump rehabilitation by Scots Pine (*Pinus sylvestris*). The results show that the Ileana Veche pit coal dump features minerals suitable for plants growth like: calcite, biotite, potassium feldspar and chemically inert one as quartz. The quantitative measurements prove that the soil minerals are enough to allow a fair growing of the *P. sylvestris* population able to start the soil type conversion from the entiantrosoil type to a more fertile one. The measurements found that the upper soil presents humus formation and features nitrogen and phosphorous while in the deeper layer are missing.

Keywords: *coal mining, coal dump, rehabilitation, mineralogy, Petroşani Basin, Romania.*

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INTRODUCTION

Petroşani is one of the main post-tectonic sedimentary basins of the Southern Carpathians. The sedimentary fillings are composed of Paleogene and Miocene deposits [1]. Several Paleogene coal beds were and still are exploited. The main coal deposits occur in the so-called “second (middle) horizon” or “lower productive”, part of the Dâlja-Uricani Formation (early Eggerian) [2]. This formation bears 22 coal beds, but only 11 are thick enough to have economic value. The sedimentary succession includes repetitive interleaving of lacustrine (bituminous shale, coal), brackish (clay, marl, dysodyle shale) and subordinate marine deposits [1-3]. The bituminous coal was under the influence of the tectonic metamorphism, i.e. pressure and temperature due to the basin compression after its filling with sediments [4]. Such mining exploitation involved coal and sterile rocks (waste rock), which is stored in sterile dumps.

Ileana Veche was the first dump resulted from Lupeni mining processes. It was built up by sterile discharging directly from the trolleys on a suspended railway system. It is oriented on east-western direction as a particularly consequence of sterile deposing. The dumping ceased in 1980. Nowadays it is fully covered by pines (*P. sylvestris*) that seem to record a healthy growth. Planting trees is a proper solution to fix and greening the coal dumps as reported in literature [5, 6]. *P. sylvestris* was also used abroad in cases of settling [7] and for plant-rehabilitation of the coal dumps [5, 6].

However, the dump was rebuilt in the last years in terraces and platforms, with low slope angles [8, 9, 34, 35]. To reduce the out-flow from the dump, two drainage systems were built, one on the northern side of the dump, which was connected to second drainage system on the western side.

According to the actual soil taxonomy, the soil covering this coal dump belongs to entiantrosoils [10, 28]. Studies on these soils issued from industrial works, in terms of composition and morphology can yield important data for dump rehabilitation [11, 12]. The landfills and dumps rehabilitation are very important works during environment ecology processing [5, 6]. Some recent studies are following this trend also in Romania [13, 11, 12].

The environmental analysis and prediction tendency are to use modern computational algorithms [14, 15]. Even the environmental rehabilitation supported computational treatment and monitoring [16]. Recently, the computational and engineering algorithms are employed to modeling physical phenomena such as thermodynamic processes [17]. Such approach could be extended to other processes such as landfill and dumps rehabilitation. Further, we develop an algorithm to evaluate the rehabilitation process of Ileana Veche sterile dump.

The measure of the dump rehabilitation is related to the satisfactory response to the critical questions raised by the designed algorithm. The specific analyses performed on the soil samples leads to an answer to the algorithm questions. Further, the algorithm shows whether the rehabilitation process is well developed or not.

RESULTS AND DISCUSSION

The sterile resulting from the technological flow of coal exploitation is deposited in waste dumps. This constitutes the dumps entiantrosoil. In this case appear certain critical questions affecting the dump rehabilitation, ie the entiantrosoil transformation into a more fertile soil [18, 19, 36]. As mentioned before [17], some operational steps could be modeled by a general logic cycle instruction as presented in Eq. (1):

$$\left[\begin{array}{l}\text{DO WHILE (CONDITIONS)}\\ \text{BEGIN}\\ \text{Cycling instructions}\\ \text{END}\end{array}\right. = LC \quad (1)$$

The algorithm could use such cycled instructions (LC) for each critical questions regarding the dump rehabilitation. Furthermore, the final algorithm will have a form like Eq. (2):

$$\left[\begin{array}{l}\text{REHABILITATION ALGORITHM}\\ \text{BEGIN}\\ LC_1 \rightarrow LC_2 \rightarrow LC_n\\ \text{END}\end{array}\right. \quad (2)$$

We designed the algorithm suitable for any pit coal sterile dump rehabilitation considering the critical questions and presented cycling instruction. The logical scheme for the designed algorithm is presented in Fig.1. and it is suitable for any programming environment. It features all elements necessary for a proper computational program; each critical question "Q" represents the cycling condition for each step meanwhile the remedy "R" represents the cycling instruction. The "remedy" is cycled while the answer to the critical condition "Q" is proper. Once a step is passed, the following step is cycled until the FINISH instruction occurs.

Our research has been made for two soil samples, one from the surface (AS_1) and another from a depth of 1 m (AS_2).

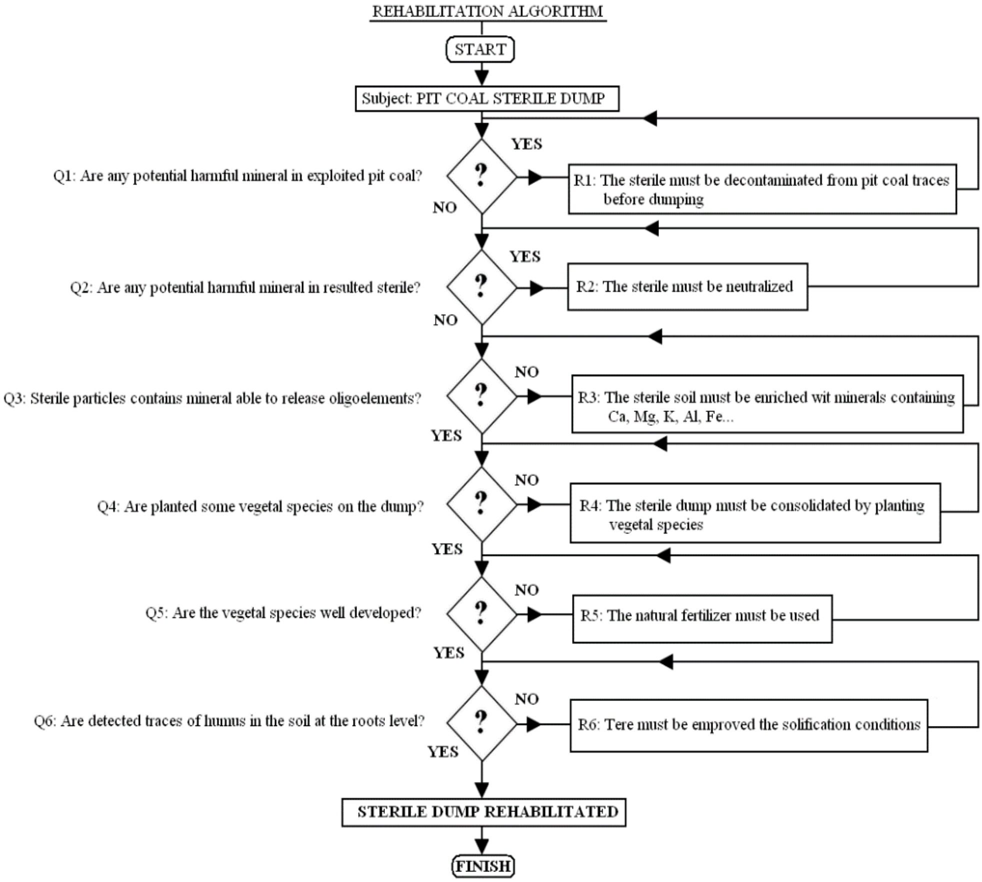

Figure 1. The sterile dump rehabilitation algorithm

Q_1 question refers to the mineralogical composition of exploited coal and the possible/potentially harmful effect to the environment. The answer to this question has been elaborated in mineralogy and crystallography analyzes achieved by average coal sample. The diffraction results are shown in Figure 2.

The general appearance of the diffractogram (fig 2.a) shows an amorphous mass base conferring a specific allure with a „hump". We observe that the overlapping variation identified distinct diffraction peaks which exceed the neutral background radiation. They are the result of the presence of accompanying minerals. Following the standard procedures has been identified these components.

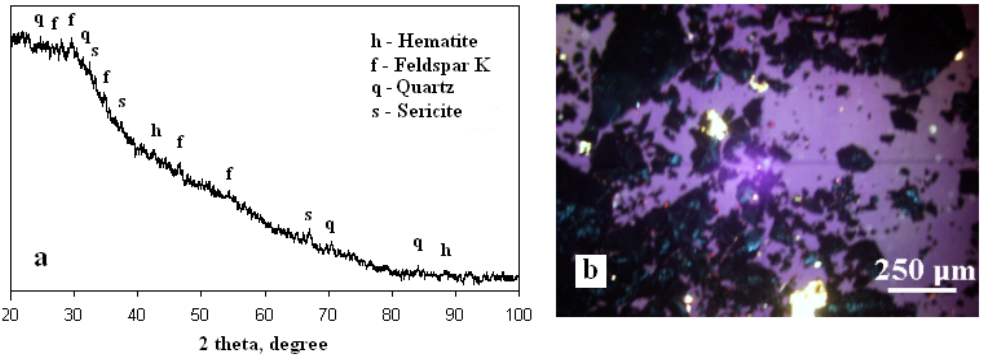

Figure 2. The pit coal from Lupeni average representative sample APCS:
a) X-ray diffraction pattern and b) optical cross polarized light microphotograph

In the coal from E.M. Lupeni have been identified the following minerals as crystalline constituents in coal sample: - SiO_2 quartz, - Fe_2O_3 hematite, sericite, $KAl_2(Si_3Al)O_{10}(OH,F)_2$, - $K(AlSi_3O_8)$ potassium feldspar.

Minerals found in the average coal sample correspond to the chemical composition reported in previous studies [20, 21, 22]. Low mineral content is proven by small peaks present in the diffractogram (fig. 2.a). Optical microscopy in polarized light confirmed the results obtained by X-ray diffraction, (fig. 2.b). Are observed quartz particles with gray-green color, with a diameter of 25 µm, potassium feldspar particles which appear bright white with a diameter of 200 µm, hematite particles which color vary from dark blue to gray and then to brown-red, depending on the particle position toward the optical microscope axis.

The diffractogram allure is specific to an amorphous material, represented by the carbon mass specific to the coal. There were identified diffraction peaks specific to quartz, potassium feldspar, sericite and hematite, but with a very low relative intensity in relation to the diffractogram background. The minimum concentration of the crystalline compound identifiable with DRON 3 diffractometer is between 1-3% depending on the specificity and sample preparation. Diffraction peaks identified in diffractogram (fig 2.a) are very close to the detection limit, because it comes from a crystalline material content a little over 3%. The fact itself indicates a very low content of crystalline material in the composition of investigated coal.

The information from literature indicates the ash content of the burning coal between 5-40% [4], that means between 5 and 40% sterile inclusions, which are usually present in crystalline form. Consequently by X-ray diffraction we can appreciate the content of crystalline material accompanying the investigated coal samples, to be around the 5%, value for the summe of crystalline compounds. Therefore the investigated coal samples from Lupeni are of the highest quality. All minerals found in the average coal sample are commonly found in the natural environment and does not generates pollution risk.

The results of elementary analyzes performed for sample are consistent with the results obtained by Rebrişoreanu 2002 [22]. The major component is the silicon from quartz. Silicon, aluminum and potassium oxides are found in potassium feldspar and sericite. Fe_2O_3 iron oxide crystallized in the rhombohedral system is present in hematite.

Crystalline inclusions from coal sample can be found in sterile dump only in certain circumstances, but their dominant effect is found in ash from burnt coal. Recent studies show that potassium feldspar and sericite is converted to mullite, while hematite is dried and becomes goetia [23]. The sterile dump is not normally exposed to intense combustion, therefore it is expected that some crystalline phases to maintain a long period of time. In addition, it is possible that some crystalline inclusions from the carbon not to be found in sterile dump due to different petrogenesis.

The answer to the critical question Q_1 is negative, which can be observed from the results of average coal sample measurements. This means that we could pass to the evaluation of critical question Q_2. This item refers to the mineralogical composition of the soil samples AS_1, AS_2, for the sterile dump Ileana Veche from Lupeni.

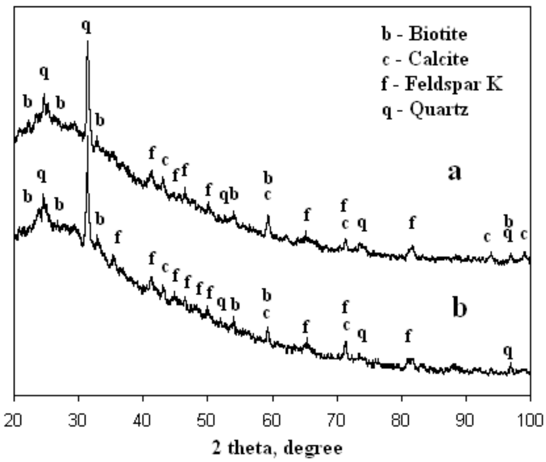

Figure 3. X-ray diffraction patterns for the soil samples collected from Ileana Veche – Lupeni sterile dump: a) AS_1 and b) AS_2

The two soil samples AS_1 and AS_2 collected from the sterile dump were investigated by X-ray diffraction and the obtained patterns are shown in Figure 3. In both samples are observed diffraction peaks well defined and different stages of crystallization.

AS_1 collected from the roots level of *P. sylvestris* is rich in quartz and potassium feldspar (minerals encountered in average coal sample). We also found significant amounts of $CaCO_3^-$ - calcite and $H_4K_2Mg_6Al_2Si_6O_{24}$ – biotite. The minerals found in AS_1 are very similar to those found in soil samples from the sea buckhtorn level roots of the West Well 7 from Vulcan sterile dump [24]. These minerals come from sterile intercalations of coal layers of sedimentary formation Dâlja-Uricani represented by sandstones and marl.

Therefore, quartz is the major component of sterile dump, about 50%, as evidenced by the diffractogram (fig. 3), in which the diffraction peaks are 100%. Diffraction peaks for other minerals not exceed 50% and are represented in AS_1 by potassium feldspar, calcite and biotite. Elemental analysis provides a more precise distribution of the elements from AS_1. Lack of hematites and sericites from AS_1 and AS_2 shows that coal is well sorted / separate from sterile.

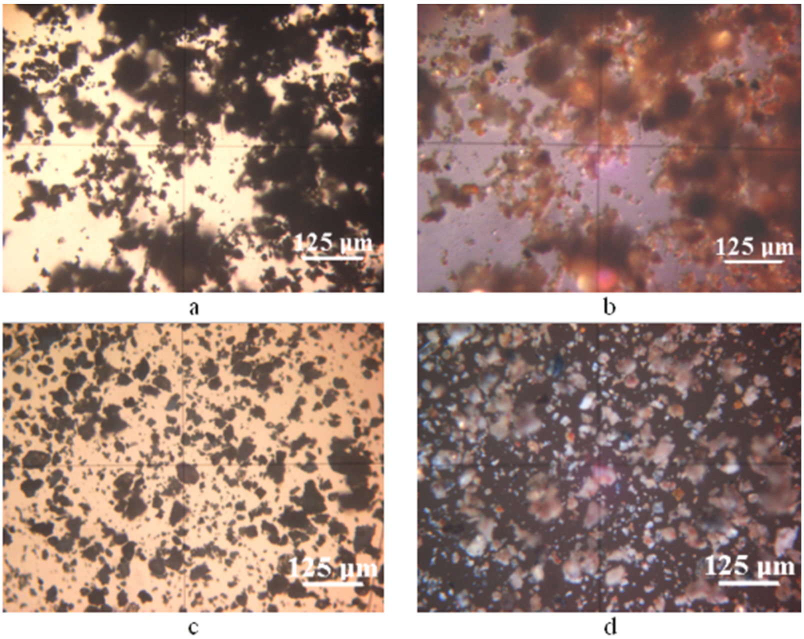

Figure 4. Optical microscopy inspection of AS_1 and AS_2 samples:
a) AS_1 transmitted light; b) AS_1 cross polarized light;
c) AS_2 transmitted light; d) AS_2 cross polarized light.

X-ray diffraction pattern for AS_2 (fig. 3) reveals similar mineralogical aspects as AS_1, because also in this sample we find quartz, potassium feldspar, biotite and calcite particles. This proves that both samples were collected from the same sterile dump and come from sediments present between coal layers from Lupeni. This gives a negative answer the critical question Q_2.

Critical question Q_3 refers to the ability of soil to release oligoelements as Ca, Mg, K, Fe, Al, useful for vegetation developement. The answer depends on the resulting data from X-ray diffraction reported to the microstructure sample.

AS_1 sample provides information about the particle size between 20 and 150 µm as shown in Figure 4.a. The distribution of particles is unusual as an aspect for industrially processed particles [23]. Further data was obtained by optical microscopy in crossed polarized light (fig. 4.b). In this figure it can be observed the quartz minerals such as grain, yellowish-brown calcite, potassium feldspar and biotite (the reddish-brown due to the presence of Fe and Mg), in diameter around 20 µm related to the organic material. The organic material is expected to be humus formed by *P. sylvestris* roots that populate the sterile dump.

AS_2 microstructure (fig. 4.c) reveals a totally different particle distribution than AS_1. The particles are well dispersed, individually disposed, without any binder. The crossed polarized light (fig. 4.d) reveals a large amount of quartz and calcite minerals, similar to spherical grains with average diameter around 20 µm, while the potassium feldspar and biotite has a lamellar - tabulated form with an average plan diameter of 15 µm. In terms of the microstructural investigations AS_2 is an initial entiantro-soil while AS_1 is a rehabilitated soil.

The quartz particles are stable physically and chemically, representing the foundation soil. Calcite particles are very sensitive to interaction with water, being able to release Ca^{2+}. Recent studies have revealed that the clay minerals are capable of releasing ions under conditions of high humidity [25, 26]. Considering this hypothesis, the AS_1 and AS_2 soils are able to provide the most important oligoelements required to develop vegetation. The potassium feldspar is able to release K^+ and Al^{3+}, while the biotite is able to release Mg^{2+} and Fe^{3+}. This is supported by X-ray fluorescence analysis for AS_1 and AS_2, the data are presented in Table 1.

Table 1. The XRF elemental analysis results for the soil samles

Compound	**Si^{4+}**	**Al^{3+}**	**Fe^{3+}**	**Ca^{2+}**	**K^+**	**Mg^{2+}**
AS_1, wt%	45.5	8.83	4.37	4.09	1.65	1.03
AS_2, wt%	49.5	8.65	4.69	3.90	1.43	0.82

The data from the Table 1 show that the sample AS_1 is able to supply enough Ca, Mg, K, Fe to sustain a vegetation developement. The answers to the Q_3 critical question is definitely affirmative, and the evaluating of the rehabilitation process could move forward to the following critical questions. The visual investigations performed on the sterile dump during the samples collection, answer affirmative to the critical questions Q_4 and Q_5, which prove that the minerals from the sterile particles are to ensure the good development of the population of *P. sylvestris*. The covering the sterile dump with pine plantations proves to be a good method of rehabilitation. The results are in accordance with previously published data [7].

A critical question to the designed algorithm remains the Q_6 question. Answering this question is beside the soil analysis, much improved and presented in Table 2 with the standards values [27].

Table 2. Results of soil formation parameters

Soil formation parameter	**Sterile dump Ileana Veche**			
	AS_1	**AS_2**	**Standard values**	**Evaluation**
pH	7.20	7.08	0-14	Neutral
Humus, %	9	0.32	2.57-15	Good content at roots level
Total nitrogen, %	0.46	0.05	0.02-0.77	Moderate content
Phosphorus, ppm	0.11	0.06	Max. 11	Low content
Potassium, ppm	60.00	20.00	Max. 96	Moderate content

The pH of the AS_1 sample is very close to neutral value, which proves the balance between the acid behavior of the feldspar and biotite particles in contact with water, than the calcite particles, which proves an excellent basic behavior. Humus value is 9% for AS_1 while as for AS_2 is almost absent. The lack of humus in depth, in AS_2 sample shows that the soil-forming agent is the life cycle of *P. sylvestris* population.

The transition from the AS_2 entiantrosoil to the fertile soil of the AS_1 sample is also evidenced by the absorption of nitrogen and phosphorus from AS_1 particles, which is closely related to pine roots action. The measured value for potassium is significant and corresponds to a common fertile soil with moderate potassium. This can be explained by the stable chemical bonds achieved of K^+ in the structure of potassium feldspar which influences the release of the K^+ ion in the aqueous solution. Finally, the answer to the critical question Q_6 is affirmative, and we can conclude that Ileana Veche dump rehabilitation is well done.

CONCLUSIONS

The designed algorithm proves to be suitable for assessing of the sterile dump rehabilitation through critical questions which refer to the influence of the soil mineralogical composition on the vegetation growth. This clearly shows that the successful rehabilitation of the sterile dump depends on the soil mineralogical composition. The designed algorithm could be developed into a proper programming environment with a better standard parameters database. It could be made in such a way to evaluate the state of sterile dump rehabilitation and to anticipate the needed measures to achieve a good level of rehabilitation. This algorithm can be applied as in the case of sterile dump West Well 7 from Vulcan which is rehabilitated with sea buckthorn or for the sterile dump from Câmpu lui Neag where we find more tree species and wild rose.

We employed a new modeling concept based on computational engineering in order to establish the relationship between the sterile soil particles composition and the dump rehabilitation by *P. sylvestris*. Our measurements established the mineralogical composition of Ileana Veche pit coal dump soils, with quartz, calcite, biotite and potassium feldspar. The minerals found in soil are also found as inclusion minerals into the pit coal, along with few traces of hematite and sericite. However, we observe that the pit coal composition do not affect the mineral composition of the sterile dump soil, organic matter being less than 1% in initial state. The quartz particles are a very good support for a proper soil formation. Calcite, biotite, and potassium feldspar represent proper vegetation source with oligoelements such Ca, Mg, K, Fe and Al in the presence of water.

The increasing value tendency of oligoelements in upper soil AS_1 was observed. Considering each modeling step evaluation, it results that the Ileana Veche pit coal dump has minerals suitable for vegetation growth (quartz, calcite, biotite and potash feldspar). The quantity of oligoelements provided by the soil minerals is enough to support the growing of the *P. sylvestris* population. According to this proposed computational model, the humus presence and the adsorption of phosphorous and nitrogen at the soil level confirms that the *P. sylvestris* population induce the transition from the entiantrosoil category to fertile one. Finally, we may conclude that the rehabilitation of Ileana Veche pit coal dump achieve a good level of rehabilitation.

EXPERIMENTAL SECTION

Soil sampling

The soil samples were collected from the top surface and from a 1 m depth (beneath the *P. silvestris* roots), in ten representative collecting locations over the dump's surface. The average representative soil samples were obtained by mixing equal amounts from each sampling point. It result the top surface average sample (AS_1) and depth average representative sample (AS_2). The pit coal samples from Lupeni exploitation were collected from at least five different sorts. Each pit coal sample was grinded and equal quantities of resulted powder were mixed into an average pit coal sample (APCS).

Mineralogical analysis

Mineralogical analysis was performed on the average samples by X-ray diffraction (XRD) analyses, using DRON 3 diffractometer with data acquisition module and Matmec VI.0 software, the X-ray characteristic being for cobalt Co kα. The diffraction peaks were identified using Standard X-Ray Diffraction Data Base – MATCH 1.0 from Crystal impact Co. The results obtained by X-ray diffraction were certified by the optical microscopy analysis, using a Karl Zeiss Jena mineralogical optical microscope.

The elemental analysis was performed according to the standard sampling and operating procedures using a Rigaku ZSX100 X-ray fluorescence spectrometer (XRF) in order to measure the main elements corresponding to the minerals identified by XRD. There was used a WDXRF wavelength detector for a wide range of atomic species. The samples were dried at 80 ºC for 12 h, powdered (325 mesh) and mixed with boric acid in a 1:4 ratio (100 mg of sample and 400 mg of H_3BO_4). The mixture was pressed at 203 MPa for 10 minutes, obtaining 2,5 cm diameter pellets of 100 mg/cm^2 surface density. The results are read with the Spectra Plus software and the determination of elements is done using Dyna Match international database. The measurements and readings were made according to EN ISO 9001:2000. The final value represents the average of reading for 3 similar samples for both AS_1 and AS_2.

The pH determination was performed on a potentiometer device INULAB®. The humus content in the AS_1 sample was measured by titration using Walkley-Black method [29, 30].

The nitrogen measurements were performed on a Panas-Wagner device according to the Kjeldahl method [31].

The phosphorus and potassium determinations were measured by Nikolov and Egner, Riehm, Domingo methods [32, 33] using a METERTECH SP 830 PLUS spectrometer.

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