Studying the Surface Radiation and Biopolymer Degradation of Soil under Normal and UV-Illuminated Conditions

Plamena Atanasova[1]*, Sabina* Nedkova[1]*,*Antoniya* Ilyeva[2] and *Dimitrina Kiryakova*[1]

[1] Department of Materials Sciences, Burgas State University, Prof. Dr. Assen Zlatarov",
Y. Yakimov Str. 1, Burgas 8010, Bulgaria
[2] Department of Chemical Technologies, Burgas State University, Prof. Dr. Assen Zlatarov",
Y. Yakimov Str. 1, Burgas 8010, Bulgaria

Abstract. The research studies the relation between the surface radioactivity of five types of soils, measured six times over three months and the biopolymer samples embedded in them, under natural conditions (ambient temperature and air humidity) and under UV radiation. The results show that clay soils (black soil – "smolnik" and forest soils) have higher indicators of surface radioactivity than sandy soil. The decomposition of the biopolymer samples embedded in the soil is faster under UV radiation conditions. A positive influence of the degraded polymer in the soil sample on reducing its surface radioactivity has been reported, more clearly expressed in soil samples subjected to UV radiation. This points out the potential of gelatin-based biodegradable polymers to influence the mobility, adsorption, and surface distribution of radionuclides in soils of different compositions. This could be used in the design of biodegradable films or packaging materials that not only minimize plastic waste but also contribute to soil radioprotection.

1 Introduction

Soil radioactivity is the result of naturally occurring radionuclides present in the environment [1, 2]. Naturally occurring radionuclides are not uniformly distributed in soils and rocks, but vary from one region to another depending on the geological, geographical and anthropogenic activities of each region [3, 4]. Soil is composed of minerals from weathered and decomposed rocks, which may contain naturally occurring radioactive nuclides, such as uranium (^{238}U) and thorium (^{232}Th) in decay series, as well as potassium (^{40}K) [5, 6]. Radionuclides are retained in the surface soil layer, where they are subject to horizontal and vertical migration over time.

Depending on its physicochemical properties, mechanical and mineral composition, the soil can absorb, retain, precipitate, and neutralize radionuclides under certain conditions. At the same time, it distributes them to plants with varying intensity, can let them through during washing and entering the groundwater can contaminate drinking water, reservoirs, etc. Thus,

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* Corresponding author: sabina_nedkova@btu.bg

the soil can serve as a barrier for radioactive contaminants to plants and fungi, but at the same time to be a reservoir that will nourish them with radioactive substances for many years. In the soil, radionuclides are found in water-soluble, exchangeable, and non-exchangeable forms, which determine their subsequent behaviour in the systems "soil-surface and groundwater" and "soil-plants". The type of soil, their mineral composition and the content of organic substances, as well as climatic conditions, affect the ability of radionuclides to move and fall into surface of the running and groundwater. These characteristics also determine the access of radionuclides to plants and fungi. The binding strength of radionuclides in the soil is one of the main factors influencing their uptake by plants. Significant differences in the uptake and accumulation of cesium (Cs) in plants have been established depending on the soil variety [7, 8]. Soils with a high humus content sorb radionuclides to a greater extent. With increasing clay content in the soil, the binding strength of the isotopes in the soil complex increases, their concentration in the nutrient solution and their absorption by the root system of plants decreases. For example, it has been established that radionuclides accumulate the least in plants grown on the black soil “smolnik”, which is a richly colloidal soil containing large amounts of montmorillonite clays. In addition, for the same soil, the absorption of radionuclides by the soil increases in the following order: ^{106}Ru < ^{90}Sr < ^{144}Ce < ^{137}Cs. Radioactive ^{137}Cs has a high absorption capacity and is least affected by soil conditions [7, 9].

Gelatin-based films are highly biodegradable, with complete degradation observed within 12 to 15 days in soil burial tests [10-14]. This rapid degradation suggests that these films do not persist long enough in the soil to have a prolonged impact on soil properties, including radioactivity, but could they act as an absorber is a question, which is a subject of our research interest.

The aim of this research is to study the relation between the presence of biodegradable polymer films based on gelatin with added glycerol, under normal conditions and under the influence of UV radiation, on the surface radioactivity of five soils with different structure, acidity and physical parameters (Soil 1 -forest coniferous, Soil 2- forest deciduous, Soil 3- cinnamon, Soil -4 black soil “smolnik and Soil 5 -light sandy soil). Although some studies have investigated the behavior of radionuclides in different soil types and their uptake by plants, there is **limited knowledge regarding the interaction between biodegradable polymer films and soil radioactivity** and the potential of **gelatin-based biodegradable polymers**, to influence the **mobility, adsorption, or surface distribution of radionuclides** in soils of different compositions. This study aims to **fill this gap** by analyzing how the presence and degradation of gelatin-based films may affect the **surface radioactivity levels** of soils with diverse physicochemical characteristics.

The novelty of this research lies in its integrated examination of biodegradable polymer–soil–radioactivity interactions. Unlike conventional studies that assess the persistence or biodegradation rate of gelatin films, this work explores their potential function as transient absorbers or mediators of radionuclide mobility under both normal and UV-affected conditions.

2 Materials and methods

2.1 Soil samples

The soil samples are taken from two spots – agricultural and forest, within the district of Burgas. The main principle of choosing the soil spots were, soils from agricultural spots, treated with fertilizers and processed with agricultural machines, or crop’s producing spots and soils from forests spots, with no treatment on. We have chosen five types of soils with different structures.

Soil 1 – Fig.1a coniferous forest soil and Soil 2 - Fig.1b deciduous forest soil belong to the brown mountain-forest soils. They are found under coniferous, mixed, and beech forests. They have a light mechanical composition, a thin humus layer, a weak accumulation of clay in the transitional horizons, and a presence of a volcanic layer in the lower part. They can be light and dark.


a) b)

Fig. 1. Optical microscopy for soil samples' surface morphology at approximately 16× magnification of Soil 1 -coniferous forest soil (a) and Soil 2-deciduous forest soil (b)

Soil 3 cinnamon - arable. This type of soil is found in dry to low forests, shrubs, and pastures, with good drainage, formed on carbonate rocks. They are rich in iron compounds, which color the soil in a cinnamon and reddish color – Fig.2a.


a) b)

Fig.2. Optical microscopy for soil samples' surface morphology at approximately 16× magnification of Soil 3-cinnamon soil (a) and Soil 4-black soil (smolnik) (b).

Soil 5 is a light sandy soil. This type of soil is poorly distributed in Bulgaria. Their sandy composition determines their qualities and properties. At a depth of up to 1 m, they contain over 65% of coarse sand, have a loose structure, do not have formed soil horizons, do not become over-moistened, which is why they lack stratification – Fig.3.

The samples were taken manually with a shovel, for each point single samples were taken from a depth of (0-10) cm. from an area, in the shape of a circle with a radius of 1 m, on a grid principle (through about 0.10 m), which were then homogenized and averaged. Forest soils, due to the coniferous (soil sample 1) and deciduous (soil sample 2) leaf mass they contain, were cleaned of larger particles (leaves, pebbles, tree bark, etc.) manually. For better distribution over the samples, the soils were roughly crushed manually.

Fig. 3. Optical microscopy for soil's sample's surface morphology at approximately 16× magnification of Soil 5- light sand soil.

The gathered data on the surface radioactivity of the five soil samples, within the three months, measured twice a month under normal and UV-Illuminated conditions, were statistically assessed with Statistical Package for the Social Sciences (SPSS). It is used to perform statistical processing and evaluation of the experimental data obtained for surface radioactivity in the different soil samples under UV-illuminated and normal conditions. The software was used for comprehensive descriptive and inferential statistical analysis, which allowed the objective assessment of variability, relationships, and significant differences of data.

2.2 Experiment

Soil samples from the five soil types are distributed in shallow containers with an area of approximately 20 cm^2. Surface radioactivity is measured in Bq eq.cm^{-1}, with the measuring probe placed above the container with the sample under study, at a fixed distance of 0.5 cm (without touching the sample to avoid contamination of the probe), in order to account for the effects of alpha and beta emitters. Measurements are made within one minute each, with the highest value reached during this time being recorded. A measuring device of the SABG-15+ probe type is used to measure surface radiation contamination from alpha, beta and gamma emitters with a working surface of 15.5 cm^2, attached to a RADIAGEM dosimetric control device, with an efficiency level above 2π, for carbon-14 (^{14}C) 17%, strontium 90 (^{90}Sr), cobalt 60 (^{60}Co) 31% and americium 241 (^{241}Am) 35%. Surface contamination is permissible in the values from 0.4 Bq.cm^{-1} for alpha emitters, up to 4 Bq.cm^{-1} for beta emitters, which can be found in the composition of tested substances that are publicly available (cannot be associated with sources of ionizing radiation) [15].

The soil samples were placed in two different environments for the period of three months, for studying the surface radiation and biopolymer degradation under normal and UV-Illuminated conditions. First group of soil samples was placed in an ambient condition (average temp. of 22-25^oC and relative humidity 42.9%). The second group of soil samples and biopolymer was irradiated by UV light with wavelengths in the interval 185–254 nm emitted by 5 lamps of 8 W each, at room temperature for the test period of three months.

Samples were retrieved after 2, 4, and 12 weeks. Changes in appearance were recorded to assess the degradation process. For assessing the biopolymer importance in surface radiation are included five couples of soils samples (so called "control" samples), placed under UV and ambient conditions.

3 Results and discussions

3.1 Soil probes' pH

The pH indicator was determined in an aqueous extract of soils in a ratio of 1:5 with the REVio Multiparam. port. pH- COND-DO Complete kit with DHS electrode. The results show that four of the five studied soils have similar pH values in the range of 7.21-7.37, and one of the soils (light sandy soil) has a lower pH value – 6.25. This is the soil which reported values of surface radioactivity for all three months of the study are the lowest among the five measured soil's surface radioactivity.

3.2 Surface radiation

Average values (mean values - MV) of surface radioactivity, measured twice a month for three months (at the middle and aprox.at the end of the months April, May and June 2025), were studied - Fig.4.

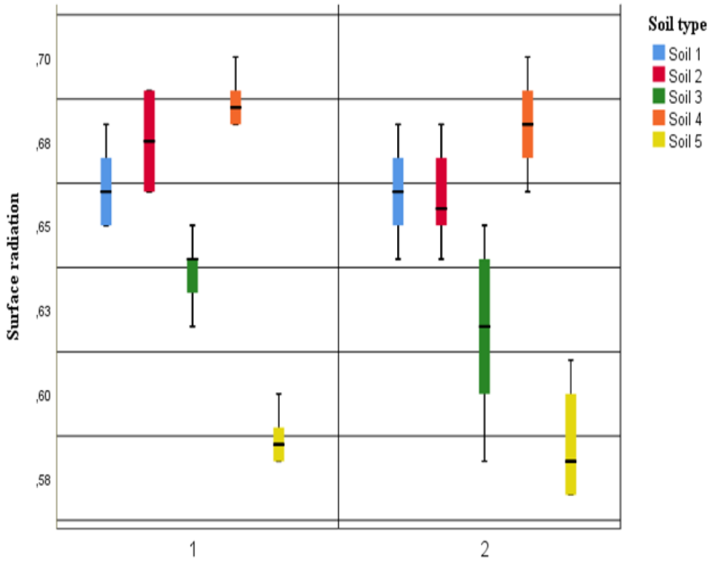

Fig. 4. Surface radiation of the five soil types - Soil 1 - coniferous forest soil; Soil 2-deciduous forest soil, Soil 3-cinnamon soil, Soil 4 - black soil (smolnik), Soil 5- light sand soil in Bq eq.cm^{-1} at ambient temperature (x=1) and under UV light (x=2).

According the average (mean values) in ascending order of their surface radiation, the soil samples are arranged from Soil 5 - light sandy with the lowest value of surface radioactivity of 0.5867 Bq eq.cm^{-1}, through Soil 3 - cinnamon, Soil 1 - forest coniferous, Soil 2 - forest deciduous and Soil 4 – black soil-smolnik with the highest values of recorded radioactivity of 0.6867 Bq eq.cm^{-1} - Fig. 5.

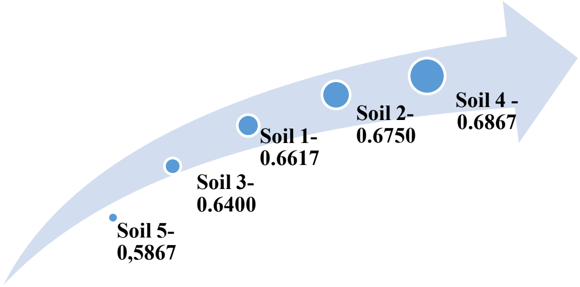

Fig. 5. Surface radiation of five soil samples

The mean values (MV) of soils with no biopolymer and with biopolymer included are summarized in Table I. (For a matter of accuracy in layering the results, the mean values in Table 1 of surface radiation of the soil samples are presented in four figures, after the decimal point). It can be seen that the average values of surface radioactivity for the measured soil samples range from 0.5850 to 0.6900 Bq eq.cm^{-1}, while for the soil samples irradiated with UV light, these values are slightly lower – Table 1 and Fig. 5. The measured values of surface radioactivity, by months, are presented in Fig. 6. It is noted that the trend is in decreasing of the values and in confirmation of the data presented in Fig. 6, the decrease is more clearly expressed in the soil samples irradiated with UV and with biopolymer inserted.

Table 1. Mean values (MV) of surface radiation of the five soil types at ambient conditions and under UV light

MV Bq eq.cm^{-1}	**Soil 1**	**Soil 2**	**Soil 3**	**Soil 4**	**Soil 5**
Control soil samples (no polymer)	0.6783	0.6817	0.6467	0.6900	0.5917
Ambient	0.6617	0.6750	0.6400	0.6867	0.5867
UV	0.6600	0.6583	0.6283	0.6800	0.5850

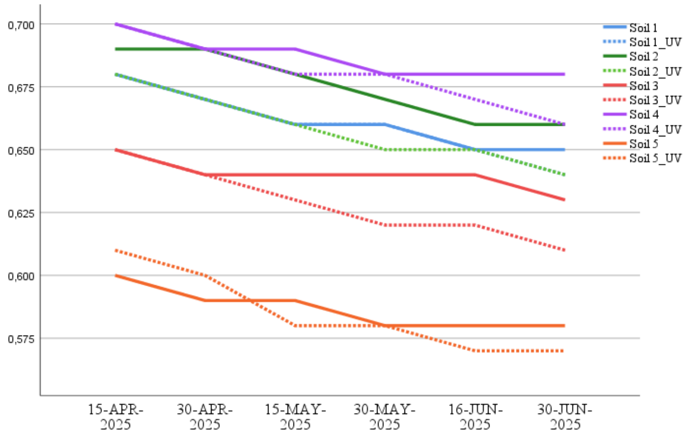

Fig.6. Surface radiation values of soil samples -Soil 1 - coniferous forest soil; Soil 2-deciduous forest soil, Soil 3-cinnamon soil, Soil 4 - black soil (smolnik), Soil 5- light sand soil and biopolymer under ambient conditions in Bq eq.cm^{-1} (solid line) and under UV light (dotted line).

4 Conclusions

For clay soils (Soil type 4 – black soil and forest Soils type 1 and 2), higher values of surface radioactivity were reported than for light sandy soil (Soil 5). The probable reason for this is that they are richer in radioactive elements than sandy soils, which may be due to their better absorption properties due to their composition. The higher humus content could sorb radionuclides to a greater extent (Soil type 4).

The reported values of surface radioactivity of soil samples without embedded polymer slightly decreased over the three months of research. This might be due to the natural process of radioactive decay.

The reported values of surface radioactivity in soil samples with embedded biopolymer decreased to a greater extent than in soil samples without polymer, in parallel with the decay of the biopolymer in them. This decrease is stronger in soils exposed to UV radiation, where polymer degradation is more pronounced. This indicates a possible relationship between the content of biopolymer particles in soil samples and the decrease in their surface radioactivity, which may be due to the absorption properties of the biopolymer.

The average values of surface radioactivity reported are in the range of 0.58 to 0.69 Bq eq.cm^{-1}. This describes the reported surface contamination as acceptable, as it is close to the values of 0.4 Bq cm^{-1} for alpha emitters and much lower than 4 Bq cm^{-1} for beta emitters, which are considered safe limits.

The findings suggest that gelatin-based biodegradable polymers may have potential as temporary radionuclide absorbers or stabilizers in agricultural soils. This property could be harnessed in the design of biodegradable agricultural films or packaging materials that not only minimize plastic waste but also contribute to soil radioprotection.

Future investigations could aim to quantify the specific mechanisms through which biodegradable gelatin-based polymers influence the retention or reduction of radionuclides in soils, as well as the influence of polymer formulation parameters (e.g., type of biopolymer, plasticizer concentration, crosslinking agents, and additives such as clay nanoparticles or activated carbon) on radionuclide binding efficiency. Since the study duration (three months) might be considered as not sufficient to fully capture long-term soil–polymer–radionuclide interactions and the analysis was focused only on overall surface radioactivity, future research could be focused on longer and more specific studies of the conclusions summarized in this study.

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