https://doi.org/10.33271/nvngu/2022-5/153

L. M. Cherniak[1],
orcid.org/0000-0003-4192-3955,
R. V. Petruk[2],
orcid.org/0000-0002-5128-4053,
O. M. Mikhieiev[1],
orcid.org/0000-0003-4763-4169,
S. M. Madzhd[3],
orcid.org/0000-0003-2857-894X,
G. D. Petruk[4],
orcid.org/0000-0002-8443-6105

1 – National Aviation University, Kyiv, Ukraine, e-mail: specially@ukr.net
2 – Vinnitsia National Technical University, Vinnytsia, Ukraine
3 – State Ecological Academy of Postgraduate Education and Management, Kyiv, Ukraine
4 – Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University, Vinnytsia, Ukraine

INVESTIGATION OF THE INFLUENCE OF HYPERTHERMIA AND SOIL POLLUTION WITH THE PETROCHEMICALS ON TEST OBJECTS USING THE METHOD OF MATHEMATICAL PLANNING

Purpose. To increase the efficiency of using methods for assessing the level of soil contamination by oil products against the background of the influence of other factors.

Methodology. The authors consider the possibility of using bioassays to study the impact of several stressors on the test system. Based on the theory of experiment planning, a methodology for researching the influence of hyperthermia and soil contamination with kerosene on the growth parameters of test objects was developed. On the basis of the obtained experimental data, regression models were built which allow finding a numerical estimate of the impact of stress factors on changes in the characteristics of the test object.

Findings. It was determined that, as a rule, in order to assess the influence of stressful factors when normalizing the assumed levels of their influence on humans and ecosystems using biotesting methods, such an assessment is carried out for individual factors. But, in the real conditions of existence of plants and organisms, they are exposed to the simultaneous influence of many factors that can interact non-additively, i.e. as antagonists or synergists. In order to increase the efficiency of the use of methods for biotesting of the level of soil contamination by oil products against the background of the influence of other factors, the authors applied one of the methods of mathematical planning of the experiment. It was concluded that the effect of one factor depends, to a certain extent, on the effect of the other factor, the effect of which was studied in the work. The fact of the non-additive effect of the factors used in the experiment makes it possible to recommend the use of test objects in the practice of monitoring the condition of soils in technogenically loaded territories previously exposed to the action of hyperthermia.

Originality. The toxic effect of the petroleum product depends, to a certain extent, on the effect of hyperthermia. Pretreatment of the test objects with a hyperthermic factor in a hormesis dose had a preventive effect, increasing the resistance of the test objects to the effect of the petroleum product.

Practical value. The fact of the non-additive effect of the factors used in the experiment makes it possible to recommend the use of test objects previously exposed to the action of hyperthermia for monitoring the condition of soils in technogenically loaded territories.

Keywords: *mathematical planning, soil pollution, petrochemicals, fuel, phytotesting*

Introduction. The modern aviation industry is developing rapidly, creating many advantages and opening up new opportunities for society [1, 2]. But, at the same time, the development of this industry creates stress for all components of the environment [3, 4]. It is known that the main problems of the negative impact of the aviation industry on the environment are air, water, and soil pollution due to emissions of harmful substances and other impacts [5, 6].

Pollution of various components of the environment at aviation enterprises has a special character [4, 7]. And, as a rule, there is a simultaneous effect of several dangerous factors, one of which is chemical pollution of environmental components with heavy metals and petroleum products, as well as thermal exposure. It has been established that, as a rule, to assess the influence of stress factors when normalizing the acceptable levels of their impact on ecosystems using biotesting methods, such an assessment is carried out for individual factors taken [8, 9]. But, as a rule, in the real conditions of existence of organisms and plants, they are exposed to the simultaneous influence of several factors that can interact non-additively, that is, as antagonists or synergists [10, 11].

Therefore, the purpose of our study was to take into account the simultaneous influence of several factors during biotesting of soil contaminated with aviation kerosene [12]. In order to further increase the effectiveness of the use of methods for biotesting of the level of soil pollution by oil products against the background of the influence of other factors, one of the methods of mathematical planning of the experiment was applied.

© Cherniak L. M., Petruk R. V., Mikhieiev O. M., Madzhd S. M., Petruk G. D., 2022

Literature review. The basics of the theory of mathematical planning of an experiment (MPE) are reflected in [13, 14]. As is known, MPE makes it possible to obtain a statistical form of the connection of system outputs with independent variables xi. In our work, to study the influence of various factors on the effectiveness of the use of biotesting of oil-contaminated soils using the method of mathematical planning, we used one of the types of MPE, namely the scheme of the complete factorial experiment (CFE).

Unsolved aspects of the problem. Each of the experiments that were conducted corresponded to an appropriate combination of factor levels [15, 16]. A certain set of levels of applied factors (factors) determines one of the possible states (certainly, in dynamics) of the object under study. The set of states of the studied system is determined by all possible sets of factor level values. In order to obtain the characteristics of all possible states of the object (within the range of factor values used by us), it was necessary to perform a series of experiments, the number of which is equal to the number of those states of the object under investigation, and which is determined by the formula

$$N = n^k,$$

where N is the number of object states; n is the number of levels (values) of each factor, k is the number of factors.

CFE allows finding the numerical values of the parameters of the mathematical model of the object under study, which is characterized by a regression equation that describes the relationship between the system output and the operating factors. This equation has the following general form $Y=f(X_1, X_2, ..., X_n)$.

This function is called the "response function". Since the actual type of the response function is unknown in advance, use a regression model of this function – its decomposition into a power series

$$Y = B_0 + \sum_{i=1}^{N} B_i X_i + \sum_{i,j=1}^{N} B_{ij} X_{ij},$$

where X_i, X_j are variables (factors); B_i, B_j are regression coefficients for the corresponding variables. The given equation is called the regression equation. Regression coefficients allow quantifying both the independent contribution of each factor ("weight", the significance of the factor) and the effects of their joint (combined) action. The latter possibility should be noted especially because it means obtaining estimates of the degree of nonlinearity (non-additiveness, varieties of which are synergism and antagonism) of factors, which is especially important for studying possible non-additive (synergistic, in particular) interaction of various factors on ecosystems in technogenically loaded territories, which include airport territories and their adjacent territories [1, 3].

Presentation of the main material and research results. We conducted a full factorial experiment, in which all possible options for combining the levels of influence of factors (temperature and toxic effect of petroleum products) were implemented. The conditions of the conducted experiment can be recorded in the form of a table, whose rows correspond to the various conducted experiments, and the columns – the values of the selected factors.

Table 1 is a reflection of the experiment planning matrix. It is presented in the table for the study of a two-factor experiment, in our case an experiment in which each of the two factors used (toxicity of oil products and hyperthermia) takes two values.

Conducting experiments according to the specified CFE scheme makes it possible to estimate the number of effects equal to the number of conducted experiments and to implement an experimental study that corresponds to this experiment planning matrix.

The analysis of the level of soil contamination by oil products – factor X_2 – was carried out using a test object subjected to hyperthermic treatment – factor X_1, which made it possible to find out how the factors chosen by us for research interact. The latter is important from the point of view of developing and improving methods for assessing the ecological state of soils in technogenically loaded territories, which include, in particular, the territories of modern airports.

The method of determining the level of soil pollution by petrochemicals using phytotesting. The required amount of the test object (lettuce (*Lactucasativa*) seeds) (210 seeds) was wrapped in filter paper in the form of an envelope. Next, the test object was subjected to hyperthermic treatment in water at a temperature of 60 °C. Processing time was 1, 3, 5, 10 and 15 min. After finishing the heat treatment, the envelopes with the test objects were dried under normal temperature conditions for a day.

Table 1

Matrix for planning of two-factor experiment

Experiment number	X_1	X_2	X_1X_2	Y_1
1	+1	–1	–1	Y_1
2	–1	–1	+1	Y_2
3	+1	+1	+1	Y_3
4	–1	+1	–1	Y_4

Marking: X_1, X_2 – factors of impact, X_1, X_2 – interaction effect, Y_i – the value of the response function

As a rule, the normalization of permissible levels of technogenic impact on humans and ecosystems using biotesting methods occurs according to individual factors. However, in the real conditions of existence of organisms, they are exposed to the simultaneous influence of many factors that can interact non-additively, as antagonists or synergists [10, 11]. In order to improve the effectiveness of the existing method for assessing the level of soil pollution by petroleum products using plant test objects against the background of the influence of other factors, one of the methods of mathematical planning of the experiment was applied [12, 13].

Next, the test object was placed in containers filled with soil (which was used as a substrate for germination) in the amount of 210 pcs.

Six soil samples were prepared for placement of heat-treated test objects:

Six samples of plants were prepared, on which heat-treated seeds were spread:

1) control sample (lettuce seeds without heat treatment);
2) lettuce seeds after heat treatment for 1 min;
3) lettuce seeds after heat treatment for 3 min;
4) lettuce seeds after heat treatment for 5 min;
5) lettuce seeds after heat treatment for 10 min;
6) lettuce seeds after heat treatment for 15 min.

On the fifth day after germination, the germination, weight of raw substance of germinated lettuce sprouts, length of their stem and root were determined. The measurement results are presented in Table 2.

The next stage of work was to establish the effect of lettuce seed treatment at a temperature of 60 °C on the growth rates of seedlings during germination on soil with different levels (concentrations) of contamination with aviation kerosene brand TS-1. Lettuce seeds were treated at the temperature of 60 °C. Processing time was 1 min. Heat treatment of seeds was performed in the same way as mentioned above.

Then lettuce seeds were sown in the plant, filled with soil, in the amount of 210 pcs. In total, 8 samples were prepared.

The first four options are soil samples with different concentrations of aviation kerosene (in multiples of CPE) for germination of unheated seeds:

1) control, soil sample not contaminated with fuel;
2) concentration of kerosene 1 APC;
3) kerosene concentration 10 APC;
4) kerosene concentration 100 APC.

Table 2

Matrix for planning a two-factor experiment

Number of experiment	A variant of the experiment	The content of aviation kerosene in the soil in relation to APC					
		1 APC		10 APC		100 APC	
1	Control sample	Y_i (root)	Y_i (stem)	Y_i (root)	Y_i (stem)	Y_i (root)	Y_i (stem)
2	$t°(1')$	Y_1 (100)	Y_1 (100)	Y_1 (100)	Y_1 (100)	Y_1 (100)	Y_1 (100)
3	Fuel (1APC)	Y_2 (138)	Y_2 (95)	Y_2 (138)	Y_2 (95)	Y_2 (138)	Y_2 (95)
4	$t°$ + Fuel	Y_3 (77)	Y_3 (92)	Y_3 (77)	Y_3 (92)	Y_3 (87)	Y_3 (75)
5	Control	Y_4 (115)	Y_4 (108)	Y_4 (115)	Y_4 (108)	Y_4 (101)	Y_4 (98)

The following four options are soil samples for germination of lettuce seeds treated at the temperature of 60 °C for 1 min:

1) control, soil sample not contaminated with fuel;
2) concentration of kerosene 1 APC;
3) concentration of kerosene 10 APC;
4) aviation kerosene concentration 100 APC.

Then the plants were placed in a package to maintain the required level of humidity and placed in a thermostat for germination at a temperature of 22 °C.

On the fifth day after germination, the growth characteristics of lettuce seedlings were determined. The results of measuring growth characteristics according to all these schemes are presented in Figs. 1–3.

From the data presented in Fig. 1, it is visible that the heat treatment of seeds for 1 min stimulated the growth activity of the root against the background of almost neutral action on the stem. Larger doses of heat treatment were inhibitory for both organs. Based on the data obtained at this stage of the study, we can assume that the effect on plants of petroleum products will depend on the initial state in which they will be – neutral (initial), hormesis (positively stimulated) or suppressed (inhibited).

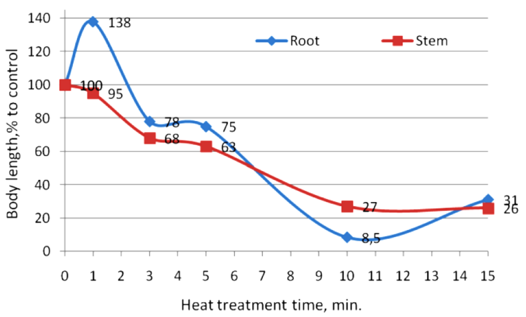

Fig. 1. Dependence of the length of the root and stem of lettuce seedlings on the time of heat treatment

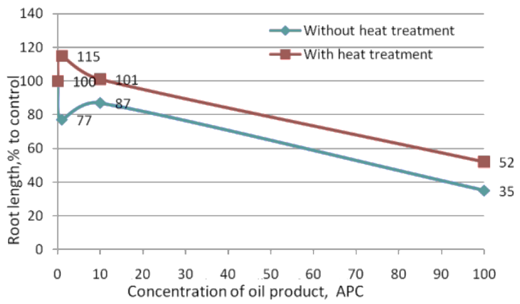

Fig. 2. Dependence of root length of lettuce seedlings (without heat treatment) and heat treatment of seeds on the concentration of oil in the soil

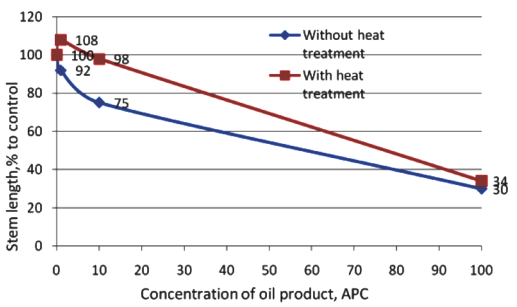

Fig. 3. Dependence of stem length of lettuce seedlings (without heat treatment) and with heat treatment on the concentration of oil in the soil

For further research, it was decided to use heat-treated for 1 min seeds, whose germination was observed to stimulate the growth activity of the root. It was supposed to reveal the nature of the interaction of the heat treatment factor in this dose with the soil contamination factor with oil product (aviation kerosene).

The use of a full factorial experiment planning matrix allowed us to determine the independent effect of individual factors used in our experimental study, namely, the effect of heat treatment of lettuce seeds at different processing times and different concentrations of oil (kerosene) in the soil. Figs. 2 and 3 present the data of the study on the combined action of these factors. It can be seen that for both the root and the stem part of the lettuce seedlings, the previous heat treatment of the seeds caused a certain protective effect and even a hormesis effect was observed for concentration of 1 APC. In order to identify the type of interaction between the heating factor and the oil factor, we used the appropriate algorithm of the CFE method.

Using the primary data of the influence of factors on the growth activity of the organs of seedlings and the planning matrix of a two-factor experiment, in accordance with which, in fact, the experiments were presented as follows – Table 2.

Using the algorithm described above, the coefficients of the regression equations were calculated. Regression coefficients, determined by the length of the root and stem of lettuce seedlings, when germinating lettuce seeds, treated for 1 min. for temperatures 60 °C for soil samples contaminated with aviation kerosene in a concentration multiple of the APC, are presented in Figs. 4–5.

Analyzing the results of calculations of the coefficient *B*1 (coefficient of the regression equation, which indicates the independent influence of temperature), we can see that with increasing kerosene concentration there is a positive effect of heat treatment on the growth activity of roots. The most positive effect of temperature is observed at the highest concentration of oil in the soil.

For the length of the stem, there was a significantly smaller positive effect of heat treatment. This can be explained by the difference in the dynamics of the impact on the root and stem. Namely, the fact that the stem later feels the flow of the toxicant.

As for *B*2 (coefficient of regression equation, which reflects the independent influence of concentration of the petroleum product in the soil), it clearly shows a negative impact

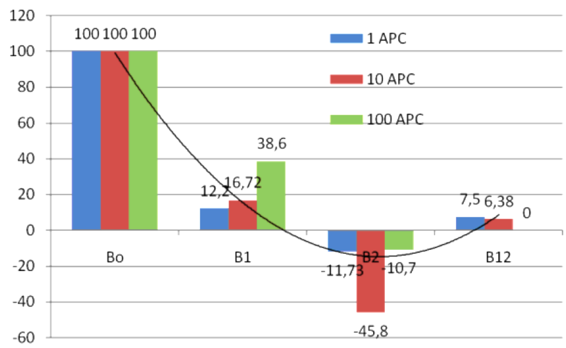

*Fig. 4. Concentration dependence of regression equations for soil contaminated with petroleum products (in relation to control sample (%) for growth parameter - root length) B*0 *is the coefficient of the regression equation for the control sample without the action of various factors*:

*B*1 *– the coefficient of the regression equation for the influence of the factor –temperature; B*2 *– the coefficient of the regression equation for the influence of the factor – the concentration of petroleum product in the soil; B*12 *– the coefficient of the regression equation for the influence of the two factors – the concentration of petroleum product in the soil and the temperature*

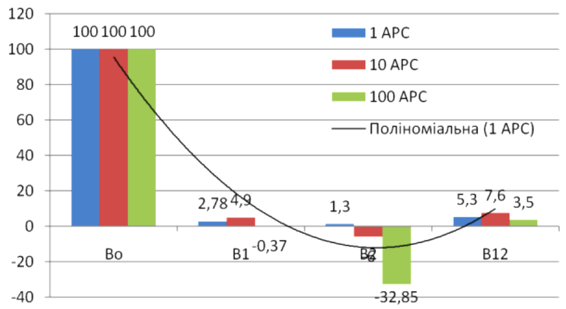

Fig. 5. Concentration dependence of regression equations for soil contaminated with petroleum products (in relation to control (%) for growth parameter – stem length) B0 is the coefficient of the regression equation for the control sample without the action of various factors:

B1 – the coefficient of the regression equation for the influence of the factor – temperature; B2 – the coefficient of the regression equation for the influence of the factor – the concentration of petroleum product in the soil; B12 – the coefficient of the regression equation for the influence of the two factors – the concentration of petroleum product in the soil and the temperature

on the development of the root system of lettuce seedlings. The fact that 10 ODC has the greatest negative impact indicates that this concentration of petroleum product in the soil may be optimal in terms of penetration into plant cell membranes.

According to the growth characteristic of the stem length of lettuce seedlings, only a noticeable effect of the maximum applied concentration of kerosene was observed. Given the fact that a negative effect on the root system was observed at the same time, the better growth parameters of the stem may be due to the indirect effect of fuel due to its absorption by the root system and inhibitory trophic and hormonal effects on the stem.

As for *B*12 (regression coefficient for the influence of two factors – the temperature of lettuce seeds and the concentration of oil in the soil), there is a low positive level of this coefficient, which indicates that the effect of the factors, however, to some extent is non-additive. In other words, although insignificant, the protective effect of hyperthermal treatment in relation to the toxic effects of the applied petroleum product can be stated.

Conclusions. Thus, it can be concluded that the effect of the toxic action of one factor (petroleum product) to a certain extent depends on the action of the other factor (hyperthermia). The fact of the non-additive effect of the factors given in the experiment makes it possible to recommend the use of test objects previously exposed to stress factors in the practice of biotesting.

In particular, with an increase in the concentration of the petroleum product in the soil up to 100 APC, a positive effect of heat treatment on the growth activity of the roots is observed. The most positive effect of temperature is observed at the highest concentration of petroleum products in the soil. As for the coefficient of the regression equation, which reflects the independent influence of the factor of the concentration of the oil product in the soil, it clearly demonstrates a negative effect on the development of the root system of plant seedlings on the example of lettuce. And the fact that the content of the petroleum product in the amount of 10 APC has the greatest negative impact indicates, in our opinion, that perhaps this concentration of the petroleum product in the soil is optimal, from the point of view of penetration into the plant cell membranes.

The obtained data indicate that pre-treatment of seeds with a hyperthermic factor in a hormetic dose had a prophylactic (hardening) effect, increasing the resistance of the studied test objects to the toxic effect of the oil product. In real conditions of existence, organisms experience the positive or negative effect of many factors (for example, temperature, radiation, etc.), which must be taken into account when assessing the level of ecological safety of technogenically loaded territories.

Therefore, the results obtained by us create a scientific and practical basis for increasing the effectiveness of the use of methods for biotesting of the level of soil contamination by oil products against the background of the influence of other factors and further improvement of the methodology for assessing the ecological state of soils in technogenically loaded territories.

References.

1. Philbin, A. (2017). *Traffic growth and air line profitability were high lights of air transport in 2016.* Retrieved from https://www.icao.int/newsroom/pages/traffic-growth-and-airline-profitability-were-highlights-of-air-transport-in-2016.aspx.
2. European Commission, Directorate-General for Mobility and Transport, Directorate-General for Research and Innovation (2011). *Flightpath 2050: Europe's vision for aviation: maintaining global leadership and serving society's needs*. Publications Office. https://doi.org/10.2777/50266.
3. Zhu, Y., Fanning, E., Yu, R.C., Zhang, Q., & Froines, J.R. (2011). Aircraft emissions and local air quality impacts from take off activities at a large International Airport. *Atmospheric Environment*, *45*, 6526-6533. https://doi.org/10.1016/j.atmosenv.2011.08.062.
4. Radomska, M.M., Madzhd, S.M., Cherniak, L.M., & Mikhyeyev, O.M. (2020). Environmental pollution in the airport impact area–case study of the Boryspil international airport. *Ecological Problems, 2*(5), 76-82. https://doi.org/10.23939/ep2020.02.076.
5. Sharmila, R., Killare, P.S., & Ki-Hyun, Kim (2012). The Effect of Aircraft Traffic Emission on the Soil Surface Contamination Analysis around the International Airport in Delhi, India. *Asian Journal of Atmospheric Environment, 6-2*, 118-126.
6. Brtnický, M., Pecina, V., Baltazár, T., Vašinová Galiová, M., Baláková, L., Bęśand, A., & Radziemska, M. (2020). Environmental Impact Assessment of Potentially Toxic Elements in Soils Near the Runway at the International Airport in Central Europe. *Sustainability, 12*(17), 7224. https://doi.org/10.3390/su12177224.
7. Masiol, M., & Harrison, R.M. (2014). Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review. *Atmospheric Environment*, *95*, 409-455. https://doi.org/10.1016/j.atmosenv.2014.05.070.
8. Cherniak, L., Mikhyeyev, O., Madzhd, S., Lapan, O., Dmytrukha, T., & Petrusenko, V. (2021). Determination of the Dependence of the Plant Growth Characteristics on the Concentration of Petrochemicals in the Soil. *Journal of Ecological Engineering, 22*(2), 226-233. https://doi.org/10.12911/22998993/131063.
9. Cherniak, L., Mikhyeyev, O., Madzhd, S., Lapan, O., Dmytrukha, T., & Korniienko, I. (2021). The usage of plant test systems for the determination of phytotoxicity of contaminated with petroleum products soil. *Journal of Ecological Engineering, 22*(6), 66-71. https://doi.org/10.12911/22998993/137363.
10. Kvaterniuk, S.M., Petruk, V.G., Frolov, V.F., Onyschuk, V.E., Wójcik, W., Pawłowski, L., & Kalizhanova, A. (2021). Restoration of the Southern Bug River Ecosystem by Removing the Biomass of Higher Water Plants. *International Journal of Conservation Science, 12*, 755-764.
11. Kvaternyuk, S., Petruk, V., Kvaternyuk, O., Bezsmertna, H., Komada, P., & Tleshova, A. (2018). Multispectral measurement of parameters of particles in heterogeneous biological media. *Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, 10808*, 108083K. https://doi.org/10.1117/12.2501590.
12. Ekundayo, E.O., & Obuekwe, O. (2000). Effects of an oil spill on soil physico-chemical properties of a spill site in a typic udipsamment of the Niger delta basin of Nigeria. *Environmental Monitoring and Assessment, 60*(2), 235-249. https://doi.org/10.1023/A:1006230025095.
13. Yeromenko, V., & Kochan, O. (2013). The conditional least squares method for the rmo couples error modeling. In *2013 IEEE 7th Inter-national Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS)*, (pp. 157-162). https://doi.org/10.1109/IDAACS.2013.6662661.
14. Chen, J., Su, J., Kochan, O., & Levkiv, M. (2018). Metrological Software Test for Simulating the Method of Determining the Ther-

mo-couple Error in Situ During Operation. *Measurement Science Review, 18*(2), 52-58. https://doi.org/10.1515/msr-2018-0008.
15. Petrusenko, V. (2015). Estimation of Ecological Human Health Risks by Influence of Non-Threshold Toxicants. *Proceedings of the National Aviation University*, (1), 89-93.
16. Hussain, I., Puschenreiter, M., Gerhard, S., Sani, S.G.A.S., & Reichenauer, T.G. (2019). Differentiation between physical and chemical effects of oil presence in freshly spiked soil during rhizoremediationtrial. *Environmental science and pollution research, 26*(18), 18451-18464. https://doi.org/10.1007/s11356-019-04819-6.

Дослідження впливу гіпертермії та забруднення ґрунту нафтопродуктами на тест-об'єкти за допомогою методу математичного планування

Л. М. Черняк[1], *Р. В. Петрук*[2], *О. М. Міхєєв*[1], *С. М. Маджд*[3], *Г. Д. Петрук*[4]

1 – Національний авіаційний університет, м. Київ, Україна, e-mail: specially@ukr.net
2 – Вінницький національний технічний університет, м. Вінниця, Україна
3 – Державна екологічна академія післядипломної освіти та управління, м. Київ, Україна
4 – Вінницький державний педагогічний університет імені М. Коцюбинського, м. Вінниця, Україна

Мета. Підвищення ефективності використання методів оцінки рівня забрудненості ґрунтів нафтопродуктами на фоні впливу інших факторів.

Методика. Автори розглядають можливість використання біотестування для вивчення впливу кількох стресорів на тест-систему. На основі теорії планування експерименту розроблена методика дослідження впливу гіпертермії й забруднення ґрунту гасом на ростові параметри тест-об'єктів. На основі отриманих експериментальних даних побудовані регресійні моделі, що дозволяють знайти чисельну оцінку впливу стресових факторів на зміни характеристик тест-об'єкту.

Результати. Визначено, що, як правило, для оцінки впливу дії стресуючих факторів при нормуванні припустимих рівнів їх впливу на людину та екосистеми з використанням методів біотестування така оцінка здійснюється для окремих факторів. Але в реальних умовах існування рослин та організмів вони піддаються одночасному впливу багатьох чинників, що можуть взаємодіяти неадитивно, тобто як антагоністи або синергісти. Авторами, з метою підвищення ефективності використання методів біотестування рівня забрудненості ґрунтів нафтопродуктами на фоні впливу інших факторів, застосовано один із методів математичного планування експерименту. Зроблено висновок про те, що ефект від дії одного фактору в певній мірі залежить від дії іншого фактору, дію яких досліджували у роботі. Факт неадитивної дії наведених в експерименті факторів дає можливість рекомендувати застосовувати у практиці моніторингу стану ґрунтів на техногенно навантажених територіях попередньо підданих дії гіпертермії тест-об'єкти.

Наукова новизна. Ефект від токсичної дії нафтопродукту в певній мірі залежить від дії гіпертермії. Попередня обробка тест-об'єктів гіпертермічним фактором у гормезисній дозі здійснила профілактичний вплив, підвищивши стійкість тест-об'єктів до дії нафтопродукту.

Практична значимість. Факт неадитивної дії наведених в експерименті факторів дає можливість рекомендувати застосовувати попередньо піддані дії гіпертермії тест-об'єкти для моніторингу стану ґрунтів на техногенно навантажених територіях.

Ключові слова: *математичне планування, забруднення ґрунтів, нафтопродукти, палива, фітотестування*

The manuscript was submitted 01.02.22.