Development of soil protection technologies in the zone of influence of airport infrastructure

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Abstract

This study presents the results of experimental research on the remediation of soils contaminated with aviation fuel, using mineral fertilizers in varying concentrations. Soil samples artificially polluted with aviation fuel were treated with nitrogen-phosphorus-potassium (NPK) fertilizers at low, medium, and high application rates. The experiment evaluated key ecological soil quality parameter such as phytotoxicity. The findings demonstrate a positive correlation between fertilizer application and the acceleration of biodegradation processes, particularly at moderate concentration levels. The results underscore the potential for integrating biostimulation techniques into broader soil protection technologies within airport zones. The study highlights the urgent need to implement soil monitoring systems and incorporate remediation practices into the environmental management strategies of airport operations.

Keywords

soil protection technologies, ecological safety, airport infrastructure, petrochemicals

1. Introduction

In the context of rapid development of transportation infrastructure, particularly air transport, the issue of anthropogenic environmental pollution—especially soil contamination—within airport impact zones has become increasingly relevant [1, 2]. Airports are key facilities in the civil aviation sector, and their operations impose considerable anthropogenic pressure on the surrounding environment [3, 4]. One of the most common types of chemical pollution in such areas is soil contamination with petroleum products, occurring both within airport premises and in adjacent territories. The components of fuels and lubricants (POL) are toxic substances capable of altering the physicochemical properties of soils, suppressing biological activity, and posing threats to human health and ecosystem stability [5, 6].

Given the absence of a dedicated soil environmental monitoring system within airport influence zones in Ukraine, there is a clear need to develop such a system, alongside effective soil protection technologies in areas affected by aviation infrastructure operations.

The aim of this article is to provide recommendations for selecting appropriate methods for monitoring the environmental condition of soils in airport-affected zones, as well as to analyze the effectiveness of soil protection technologies against petroleum contamination through the application of mineral fertilizers.

An analysis of the current situation regarding soil contamination by petroleum products within airport impact zones reveals that the main sources of this type of chemical pollution include [7, 8]: aviation fuel leaks during refueling and other fuel-handling operations; maintenance of ground vehicles; accidental spills; and stormwater runoff from aircraft parking areas, runways, and hangars. Particularly

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concerning is the fact that, apart from accidental spills, soil contamination by petroleum products is often persistent and not immediately evident, but over time it leads to soil degradation, deterioration of physicochemical and ecological properties, and the accumulation of toxic substances in the biosphere [9, 10].

Petroleum contamination can result in changes to organic matter content, disruption of the soil profile structure, alteration of the water–air regime, and the emergence of hydrophobic properties that inhibit water and oxygen infiltration. These changes reduce microbiological activity, suppress soil microorganisms and fauna [11], and disrupt the natural self-purification processes of the soil [9]. Importantly, contamination by petroleum products is often persistent and cumulative; without the application of remediation technologies, such substances can remain in the soil for decades.

Environmental safety within airport zones is a matter of strategic importance, especially considering that such facilities are typically located near densely populated areas. Soil contamination can lead to secondary pollution of surface and groundwater, as well as air pollution due to the volatilization of light petroleum fractions. However, Ukraine currently lacks a comprehensive system for monitoring soil quality in airport-affected zones, which hinders early detection and management of pollution. In many cases, available information on soil conditions is either fragmented or outdated, preventing timely decision-making and the development of effective soil remediation recommendations.

Among the most accessible and promising technologies for protecting and restoring soils contaminated by petroleum products is bioremediation [12, 13, 14, 15, 16], which is gaining wider application in recent years.

In light of the above, the development and implementation of a soil monitoring system in areas influenced by airports is of critical importance. Such a system should include:

- a network of permanent sampling points for soil collection;
- a clearly defined list of monitored parameters (including petroleum hydrocarbons and heavy metals);
- the application of modern physicochemical and biological methods;
- the establishment of a digital database with spatial visualization of results (e.g., using GIS technologies);
- a system for interpreting and assessing environmental and public health risks in areas affected by airport operations.

Ensuring an adequate level of soil environmental safety in airport impact zones is only possible through the integration of a soil environmental monitoring system into the overall environmental management strategy of airports. According to the proposed recommendations, environmental monitoring should not be limited to periodic sample collection, but must form part of a continuous process of environmental assessment, planning, and decision-making to ensure soil safety in these areas.

The implementation of soil environmental monitoring must include the mandatory assessment of soil phytotoxicity [17], as soil is a key environmental component that plays vital functions within the biosphere.

2. Materials and methods

To assess the phytotoxicity level of soil artificially contaminated with TS-1 aviation fuel, the standard biotesting method known as the "growth test" [18] was employed. The experimental methodology involved the preparation of nine soil samples, which were placed into Petri dishes in a predetermined amount. Mineral fertilizers were added to all soil samples except the control (clean soil sample) in the following NPK ratios: 15:9:24, 20:20:20, 18:11:15, and 13:40:15. Additionally, four of the samples were supplemented with TS-1 fuel at a concentration of 10 MPC (Maximum Permissible Concentration). The soil samples were incubated in a thermostat at a temperature of 22 degrees. On days 5, 10, 15, 20, 25, and 30, samples were collected for biotesting in order to calculate the phytotoxicity index of the tested soils [19].

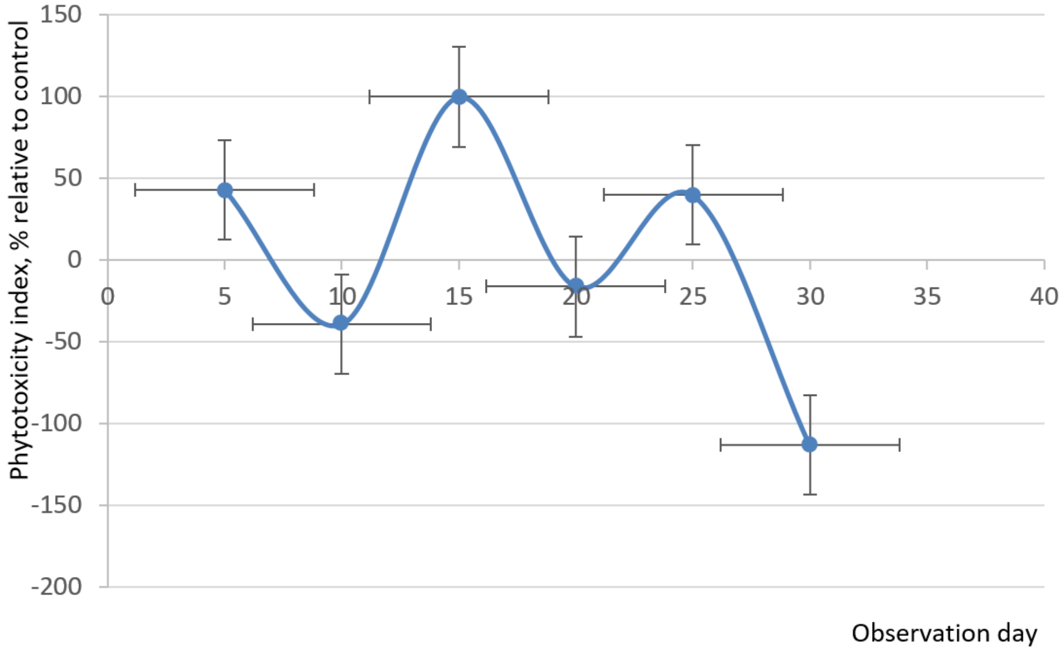

Figure 1: Dynamics of changes in the soil phytotoxicity index (% relative to the control) following the application of fertilizer with an NPK ratio of 15:9:24.

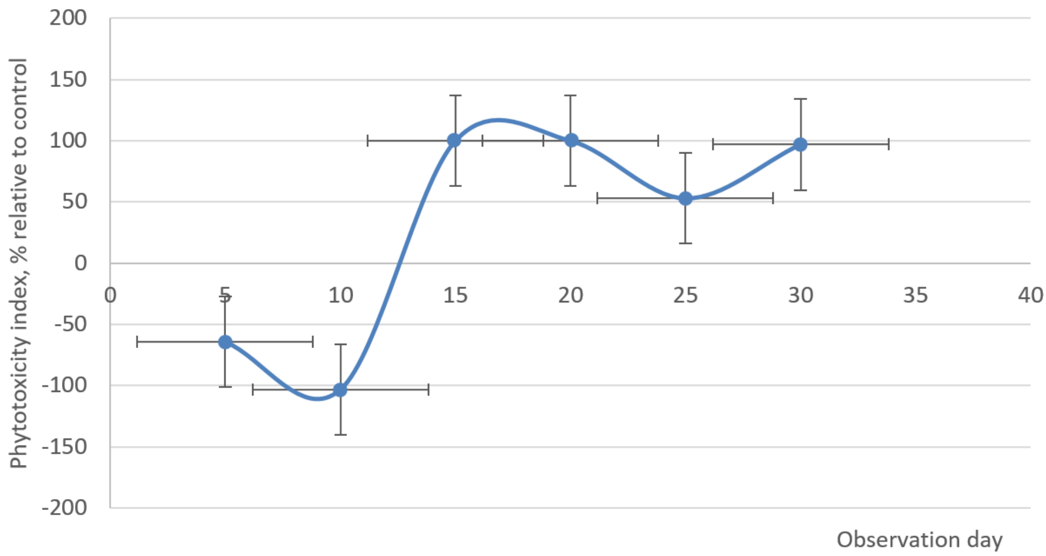

Figure 2: Dynamics of changes in the soil phytotoxicity index (% relative to the control) following the application of fertilizer with an NPK ratio of 20:20:20.

3. Results

The results of calculating the soil phytotoxicity index are presented in Figures 1 - 8.

As shown in Figure 1, a reduction in soil recovery is observed on day 30 of the study when using the NPK 15:9:24 mineral fertilizer, compared to the control. For the soil sample with the addition of NPK 20:20:20 fertilizer, an improvement in the soil's ecological characteristics is observed between days 5 and 10, after which the phytotoxicity index approaches that of the control (Figure 2).

For the soil sample with NPK 18:11:15and the addition of aviation fuel (Figure 3), an increase in the phytotoxicity index is observed on the 20th day of the study, followed by a decline in phytotoxicity levels comparable to those at the beginning of the experiment.

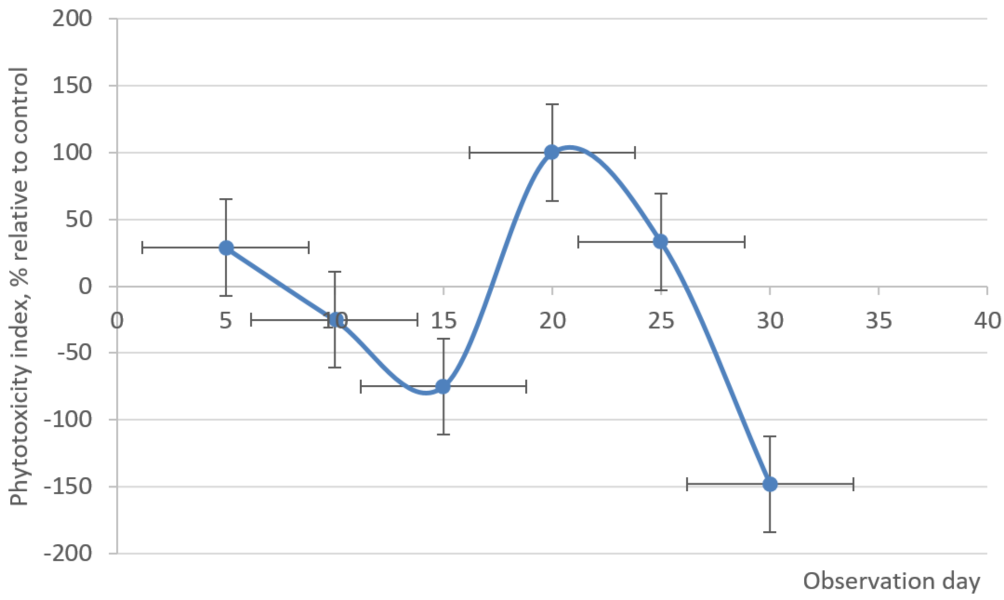

Figure 3: Dynamics of changes in the soil phytotoxicity index (% relative to the control) following the application of fertilizer with an NPK ratio of 18:11:15.

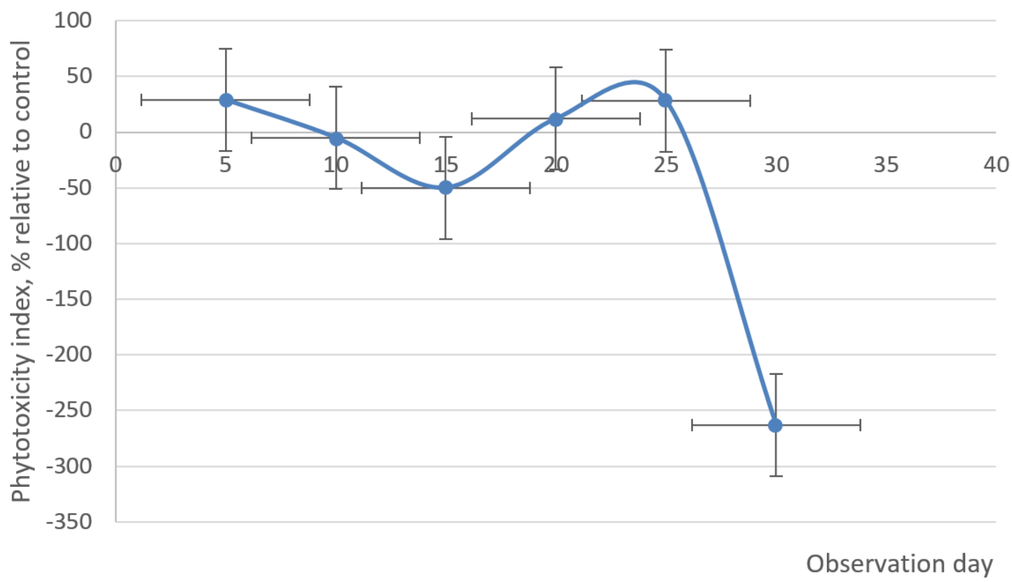

Figure 4: Dynamics of changes in the soil phytotoxicity index (% relative to the control) following the application of fertilizer with an NPK ratio of 13:40:15.

For the soil sample with NPK 13:40:15and the addition of aviation fuel (Figure 4), an increase in the phytotoxicity index is observed on the 25 day of the study, followed by a decline in phytotoxicity levels comparable to those at the beginning of the experiment.

For the soil sample with NPK 15:9:24 and aviation fuel (Figure 5), a decrease in the phytotoxicity index is observed on the 20th day of the study, followed by a reduction in phytotoxicity levels comparable to those at the beginning of the experiment.

For the soil sample with NPK 20:20:20 and aviation fuel (Figure 6), a decrease in the phytotoxicity index is observed on the 25th day of the study, followed by a reduction in phytotoxicity levels comparable to those at the beginning of the experiment.

For the soil sample with NPK 18:11:15 and aviation fuel (Figure 7), a decrease in the phytotoxicity

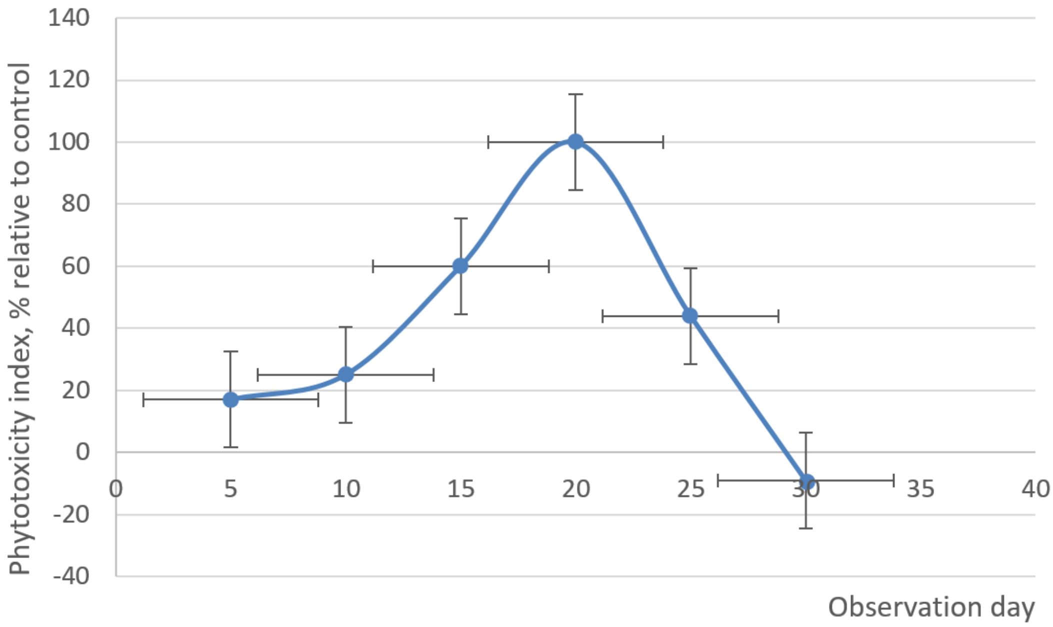

Figure 5: Dynamics of changes in the soil phytotoxicity index (% relative to the control) in soil artificially contaminated with 10 MPC of TS-1 aviation fuel, following the application of fertilizer with an NPK ratio of 15:9:24.

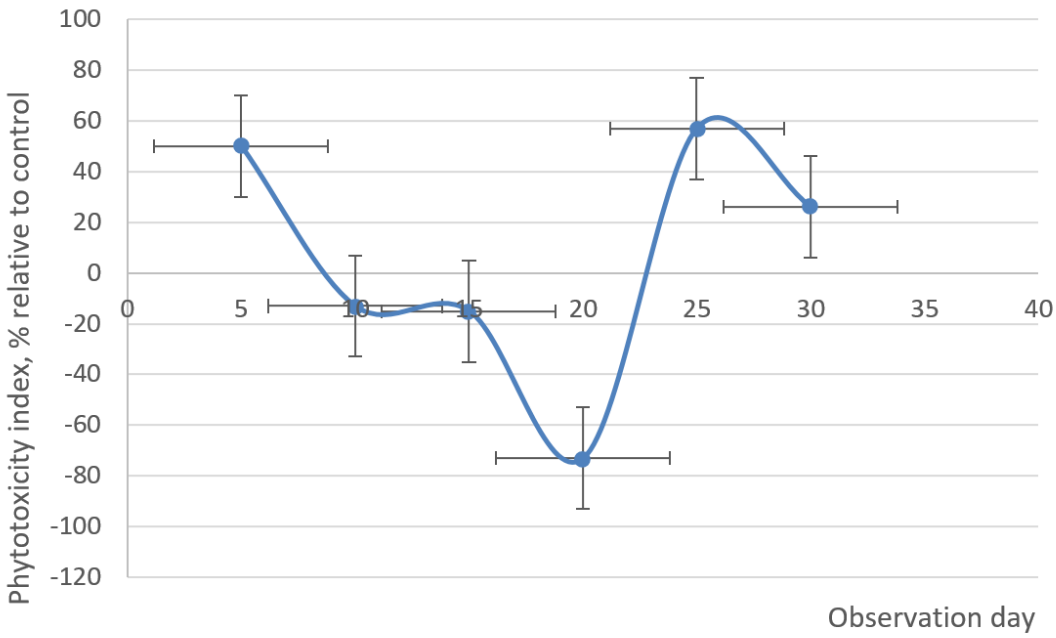

Figure 6: Dynamics of changes in the soil phytotoxicity index (% relative to the control) in soil artificially contaminated with 10 MPC of TS-1 aviation fuel, following the application of fertilizer with an NPK ratio of 20:20:20.

index is observed on the 10, 20 and 25 days of the study, followed by a decline in phytotoxicity levels comparable to those at the beginning of the experiment.

For the soil sample with NPK 13:40:15 and aviation fuel (Figure 8), a decrease in the phytotoxicity index is observed at the initial stage of the study, followed by a decline in phytotoxicity levels comparable to those at the beginning of the experiment.

Analyzing the obtained experimental results (Fig. 9) based on biotesting to assess the impact of mineral fertilizer application on soil phytotoxicity levels, we can conclude that the use of mineral

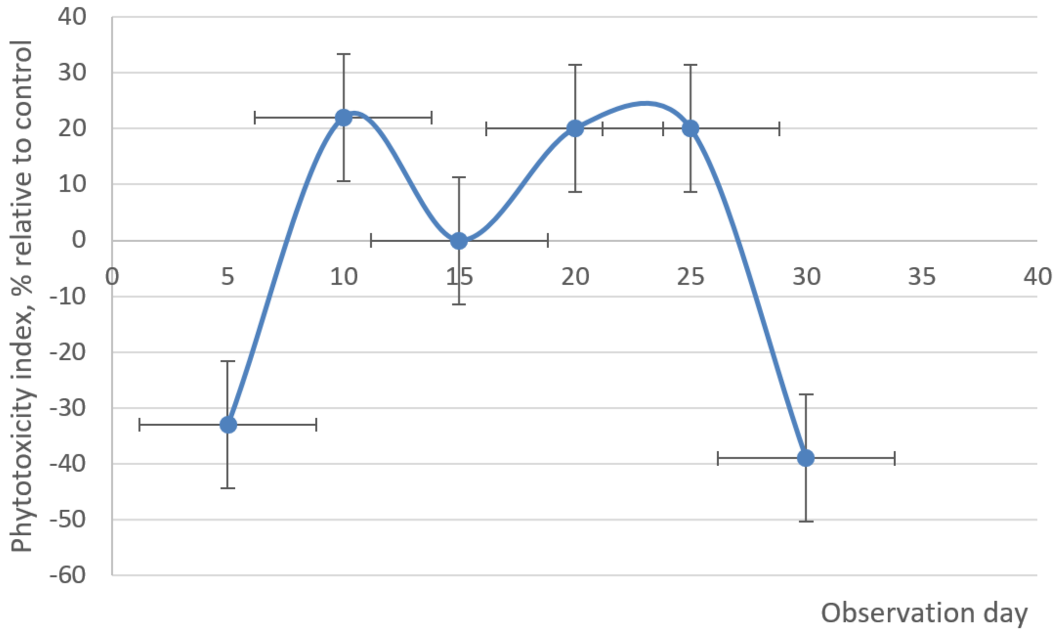

Figure 7: Dynamics of changes in the soil phytotoxicity index (% relative to the control) in soil artificially contaminated with 10 MPC of TS-1 aviation fuel, following the application of fertilizer with an NPK ratio of 18:11:15.

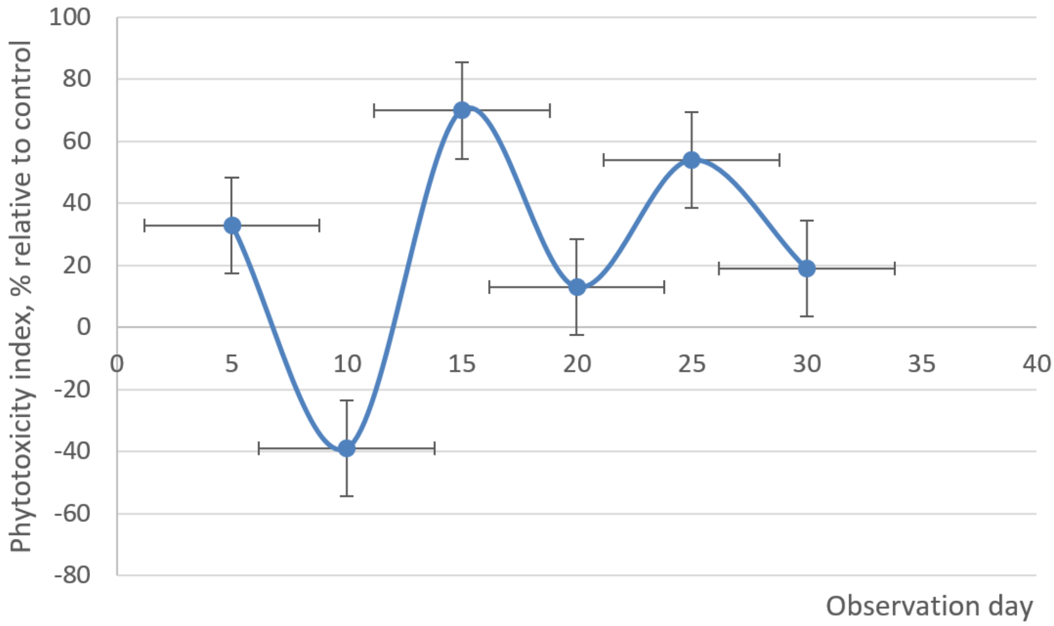

Figure 8: Dynamics of changes in the soil phytotoxicity index (% relative to the control) following the application of fertilizer with an NPK ratio of 13:40:15.

fertilizers is effective in soil protection technologies for areas contaminated with aviation fuel.

Therefore, depending on the NPK of the mineral fertilizer and the concentration of petroleum products, the required degree of soil restoration can be achieved in the technogenically loaded areas in the airport's impact zone.

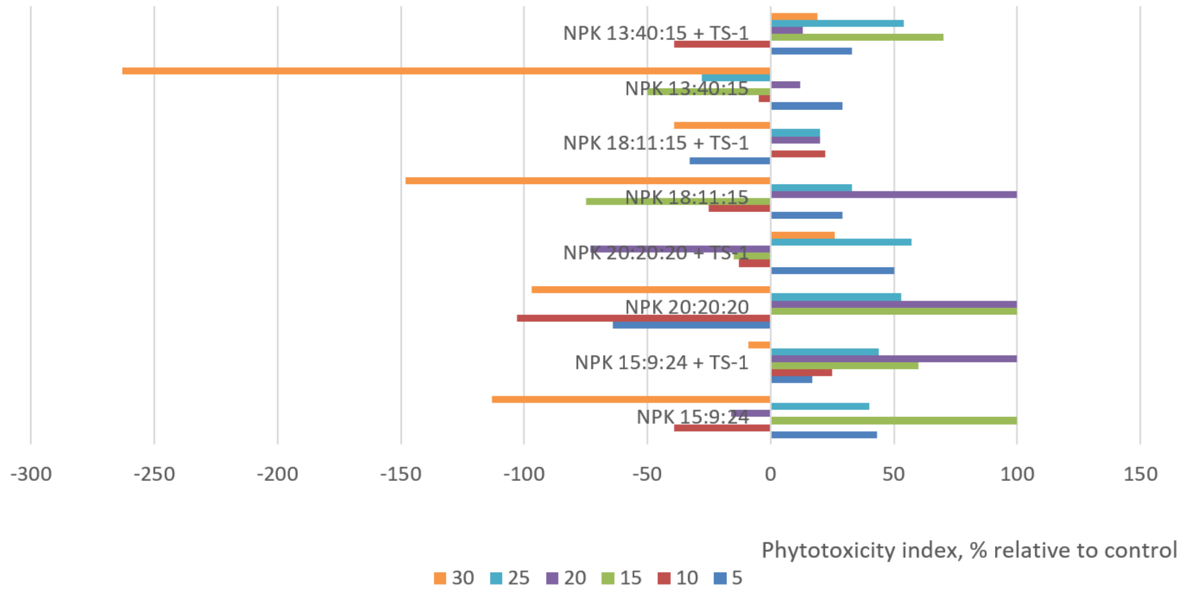

Figure 9: Phytotoxicity index comparison among various soil samples.

4. Conclusions

As a result of the analysis of the obtained experimental data, it can be concluded that the soil phytotoxicity index shows promise for use in the development of an environmental monitoring system for soils in areas affected by aviation infrastructure facilities. In particular, it is relevant when applying soil remediation technologies for areas contaminated by petroleum products. The effectiveness of using mineral fertilizers has been established in the development of modern soil protection technologies in zones subject to technogenic impact from aviation infrastructure.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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