ANALYSIS OF INSTRUMENTAL METHODS IDENTIFICATION OF XENOBIOTICS TO REDUCE SOIL POLLUTION

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Abstract: *Soil pollution with xenobiotics is a major ecological problem, with significant implications for ecosystem health, biodiversity and human health. Xenobiotics, especially pesticides, herbicides and fungicides, are widely used in agriculture, but their long-term effects on soil quality are increasingly evident. This article aims to analyse the impact of the use of these substances on the soil and highlight sustainable methods to combat soil pollution.*

Keywords Soil pollution, xenobiotics

1. INTRODUCTION

Soil pollution is one of the most pressing contemporary ecological challenges, with profound implications for human health, biodiversity and the functionality of terrestrial ecosystems. This form of environmental degradation is predominantly driven by anthropogenic activities, including the intense and uncontrolled application of chemical fertilisers and pesticides, the dumping of toxic substances, and the inadequate landfilling of industrial and municipal waste. The cumulative impact of these practices leads to irreversible deterioration of soil quality, compromising the ecosystem services it provides – from sustaining agricultural production, to water filtration and carbon sequestration.

In the context of climate change and increasing pressure on natural resources, sustainable soil management is becoming a strategic priority. In this respect, reducing the use of xenobiotics – especially synthetic pesticides – is recognised as a central objective in environmental and agricultural policies at national and international level. Recent European Union strategies, such as the Green Deal and the Farm to Fork initiative, promote reducing the impact of chemicals on soil by encouraging agro-ecological practices and supporting research into environmentally

friendly alternatives. Thus, protecting the quality of soil and associated ecosystems is essential for the transition to a circular, resilient and environmentally sustainable economy.

Xenobiotics are synthetic chemicals, with no natural correspondence in the environment, characterized by a high resistance to biodegradation processes. This category includes pesticides, herbicides, fungicides, industrial compounds and heavy metals. These substances are widely used in various fields, such as agriculture, industry, medicine, but also in everyday life. In particular, in the agricultural sector, pesticides and herbicides are applied for the management of phytopathogens and other crop pests. However, the literature consistently highlights their negative impact on the soil (Smith et al., 2019), manifested by affecting beneficial microorganisms, reducing fertility and compromising the regenerative capacity of pedological ecosystems.

The effects of xenobiotics on soil are manifested by a variety of mechanisms that disrupt essential natural processes. Many of these substances have a pronounced toxicity on edaphic microorganisms involved in the degradation of organic matter and in the dynamics of biogeochemical cycles. The disruption of these microbial communities leads to a significant decrease in the efficiency of nutrient recycling processes, directly affecting soil fertility. Moreover, certain xenobiotics can inhibit biological nitrogen fixation – an essential process in plant nutrition – which contributes to the decline in agricultural productivity in the long term (Pereira et al., 2021).

Another major effect is the tendency of these compounds to accumulate in the soil and, subsequently, to penetrate the food chains. Xenobiotics do not only exert toxicity on the soil, but also on plant and animal organisms, including humans. Through absorption by plants, chemicals can end up in food, posing health risks to consumers. Some pesticides are well known for their neurotoxic and carcinogenic potential (Gomez et al., 2020). Bioaccumulation and biomagnification compound this risk, as toxic substances become progressively concentrated as they move up the food chain, culminating in human exposure.

An	România (tone)	Media UE (tone)
2010	10.500	350.000
2011	10.800	355.000
2012	11.200	360.000
2013	11.500	365.000
2014	11.800	370.000
2015	12.100	375.000
2016	12.400	380.000
2017	12.700	385.000
2018	13.000	390.000
2019	13.300	395.000
2020	13.600	400.000
2021	13.900	405.000
2022	14.200	410.000

Fig.1.Pesticide consumption in Romania vs. EU average (2010–2022)

In the context of globalization and the intensification of agricultural production necessary to meet the needs of a growing population, the problem of the use of xenobiotics is becoming increasingly acute. Although current research provides clear evidence on the negative impact of these substances on the environment, institutional responses and remedial measures often remain insufficient or unevenly applied. Thus, it becomes imperative to promote policies to reduce the use of xenobiotics and to invest in the development of environmentally friendly, effective and safe alternatives for crop protection and soil health.

The consumption of pesticides in Romania compared to the average of the European Union is presented in Tab. 1 and Fig. 1, which shows the evolution of pesticide consumption expressed in tonnes, recorded in Romania, compared to the average of the European Union Member States, over a relevant period. The data highlight the differences in use and allow a comparative analysis of agricultural practices from the perspective of sustainability and impact on the soil.pesticide consumption in Romania compared to the European Union average until 2023.

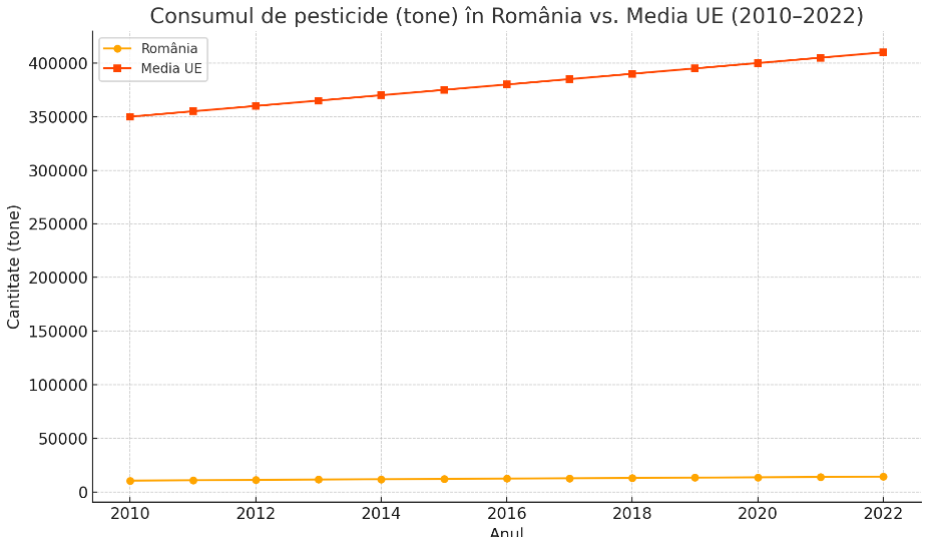

Fig 2. Graphical interpretation of pesticide consumption2010-2022

2. DESCRIPTION OF STUDIES

One of the most obvious effects of soil treatment with pesticides is the disruption of the biodiversity of soil microorganisms. Healthy soil is home to a wide range of microorganisms, including bacteria, fungi, actinobacteria, and nematodes, which play a crucial role in maintaining fertility and recycling nutrients. In Romania, recent studies have shown that pesticides can significantly affect the composition and activity of these microorganisms. For example, research conducted by Popescu et al. (2020) in agricultural regions in the south of the country demonstrated that the repeated use of pesticides reduces the diversity of bacteria in the soil, with a particular impact on nitrogen-fixing bacteria. These bacteria are essential for the natural fertilization process of the soil, and reducing their numbers can lead to a decrease in the availability of nitrogen to plants.

Studies carried out on soils in Romania have also identified negative effects on fungal activity. In a study conducted in agriculture-intensive regions, Tudor et al. (2019) observed that fungicides applied to combat plant diseases affect the functioning of fungal mycelium, which is essential for the decomposition of organic material and nutrient recycling. These chemicals,

which are applied in high doses to control pathogens, not only destroy harmful microorganisms, but also affect beneficial organisms, disrupting the natural balance of the soil.

Regarding the impact on soil structure, research conducted by Păun et al. (2021) in agricultural areas in central and western Romania showed that the application of pesticides can lead to a decrease in the activity of some fundamental processes of formation and maintenance of soil structure. Pesticides can affect the activity of nematodes and other organisms that contribute to soil aeration and pore formation, which are essential for water drainage and oxygen circulation. Thus, repeated treatments with chemicals can lead to soil compaction and a decrease in its ability to support plant life.

Another important aspect in national research is the long-term impact of pesticides on their residues in the soil. In a project carried out by Ionescu et al. (2022) in several regions of Romania, the persistence of chemicals in soils treated with pesticides was investigated. The results showed that some of these chemicals can remain active in the soil long after application, and their concentrations can increase depending on the type of pesticide and the frequency of application. For example, in soils treated with organophosphate insecticides and carbamates, research has shown that residues of these substances can remain in the soil for more than a year, which increases the risk of plants and organisms being exposed to toxic substances in the long term.

An important result of the research carried out on Romanian soils is the observation of the effects of pesticide residues on plants and the quality of agricultural products. Studies by Munteanu et al. (2020) have shown that some pesticide residues can negatively affect plant roots and reduce their ability to absorb essential nutrients such as phosphorus and potassium. In addition, residues can accumulate in fruits and vegetables, which poses a danger to consumers. Following the application of pesticides, the quantities of chemicals can reach dangerous levels, and this contamination has direct implications for public health.

Studies conducted in Romania have also highlighted the effects of pesticides on groundwater, an aspect that is often interconnected with soil pollution. Recent research by teams of researchers from the University of Agronomic Sciences in Bucharest has shown that pesticides, by infiltrating the soil, can reach the water table and contaminate drinking water resources. The results obtained by Toma et al. (2021) indicate that in the intensely agricultural regions of the country, pesticide concentrations in groundwater often exceed the limits allowed by European regulations, endangering the health of the population and aquatic ecosystems.

Research on the biology of soils treated with pesticides in Romania highlights the significant impact of these substances on soil biodiversity, water quality and public health. National studies have revealed the long-term effects of pesticides on soil structures and organisms, as well as the risks of contamination of water and agricultural products. In the face of these challenges, research continues to promote sustainable solutions and environmentally friendly technologies to reduce the impact of pesticides on the environment and protect the country's natural resources.

3. COMBATING SOIL POLLUTION WITH PESTICIDES (XENOBIOTICS)

Combating soil pollution with pesticides (xenobiotics) is a major global challenge, which requires innovative and sustainable approaches to protect the health of the environment and natural resources. Pesticides, although essential in pest control and protection of agricultural crops, have significant negative effects on the soil, its biodiversity and, implicitly, on human health. Soils frequently treated with pesticides risk becoming infertile in the long term, and their

contamination with persistent chemicals is a complex problem that requires effective management measures.

Pesticides are chemicals used to combat pests in agriculture, but their effects on the soil can be devastating. One of the most obvious impacts is the disruption of the ecological balance in the soil, especially through the reduction of microbial diversity. Soil microorganisms are essential for breaking down organic matter, recycling nutrients, and maintaining soil structure. When pesticides are applied repeatedly, they can negatively affect bacteria, fungi, and other microorganisms, which play crucial roles in the natural fertilization process of the soil (Gomez et al., 2020). In a study conducted in the agricultural regions of southern Romania, Popescu et al. (2020) found a significant decrease in the populations of nitrogen-fixing bacteria, essential for supporting soil health. Thus, the uncontrolled use of pesticides contributes to reduced soil fertility and dependence on chemical fertilizers, which can become an unsustainable practice in the long term.

The negative impact of pesticides on the soil is related to their persistence in the environment. Many of the chemicals used in agriculture do not break down quickly and can remain active in the soil for long periods, sometimes even decades, depending on the type of pesticide used and environmental conditions. Pesticide residues can penetrate deep soil layers, contaminating groundwater resources and creating significant public health risks (Pereira et al., 2021). An example of this is the study carried out in the regions of southwestern Europe, where pesticide residues in the soil were detected in groundwater, exceeding the limits allowed by European regulations (Müller et al., 2019). These substances can thus end up in the food chain, affecting not only the soil, but also the organisms that consume the contaminated plants, including animals and humans.

Tackling soil pollution with pesticides requires a change in the agricultural approach that reduces reliance on chemicals and promotes greener alternatives. An important first step in this direction is to promote sustainable agriculture, using more natural methods of pest control. Organic farming, for example, promotes the use of compost, organic fertilizers, and natural pest control methods, such as crop rotation and the use of plants that attract beneficial insects. These practices reduce the need for chemical pesticides and help maintain high biodiversity in the soil. According to a study by Li et al. (2020), adopting such practices can help restore microbial diversity and improve soil health in the long term, thus helping to combat soil pollution with chemicals. Innovative technologies, such as precision farming, can also play a significant role in reducing the use of pesticides and their impact on the environment. Precision agriculture uses monitoring systems, sensors, and GPS to apply pesticides exactly where they are needed, so that the amount of chemicals used is minimized. Studies conducted in the United States and the European Union have shown that these technologies can significantly reduce the amount of pesticides applied while protecting soil health and water resources (Thompson et al., 2021). For example, research from the University of California Agricultural Sciences has shown that the use of precision technologies can reduce pesticide application by up to 30%, which helps limit soil and water contamination.

Additionally, government regulations and farmer education play a critical role in reducing soil pollution from pesticides. The European Union, for example, has implemented policies and regulations aimed at reducing the use of pesticides and promoting more sustainable agricultural practices. The European Commission's Farm to Fork Strategy highlights the importance of reducing the use of chemicals in agriculture, by supporting research and innovation, but also by educating farmers about environmentally friendly alternatives. Strict regulations and

monitoring their application are essential to reduce the impact of pesticides on the environment. Studies by Garcia et al. (2020) have shown that strict regulations and farmers' awareness campaigns can significantly reduce the use of harmful pesticides and help protect soil and ecosystems. Another important factor in combating soil pollution by pesticides is to promote research and development of more environmentally friendly and less toxic pesticides. In recent years, research into organic pesticides has advanced considerably, and many of these products have a much lower impact on soil and ecosystem health. For example, pesticides based on beneficial microorganisms or natural plant extracts are increasingly used as environmentally friendly alternatives for crop protection, being less toxic to the soil and the organisms in it (Smith et al., 2020). Recent research has also shown that the use of biological technologies, such as fungicides based on bacteria or fungi, can reduce the need for chemical pesticides and help maintain soil health.

Combating soil pollution with pesticides is a complex process that requires an integrated approach, which includes both effective public policies and technological innovation and education. Promoting more sustainable agricultural practices, using precision technologies and developing environmentally friendly alternatives to chemical pesticides are essential in protecting soil and ecosystems from the harmful effects of pesticides.

The essential measures in combating soil pollution is the promotion of sustainable agricultural practices. Intensive agriculture, based on the excessive use of pesticides and chemical fertilizers, has led to severe soil degradation, and reducing dependence on these substances is an important step in preventing pollution. Organic farming, which relies on natural pest control methods and the use of organic fertilisers, can play a key role in protecting the soil.

Recent studies have shown that adopting such practices not only reduces the impact on the soil, but also improves biodiversity, helping to maintain the health of soil ecosystems (Smith et al., 2019). Organic farming also promotes crop rotation and diversification, which helps maintain soil structure and prevent soil erosion.

Also, the use of innovative technologies, such as precision agriculture, can significantly contribute to reducing soil pollution. Precision agriculture uses advanced technologies, such as sensors and GPS, to apply exactly the necessary amounts of fertilizers and pesticides, avoiding overuse and reducing the risks of soil and water contamination (Thompson et al., 2021). These technologies allow farmers to apply chemicals only in areas where they are needed, which minimizes environmental impact. Research has also shown that more precise application of pesticides can significantly reduce the negative effects on soil microorganisms and its biodiversity (Li et al., 2020).

The results of national and international research indicate that the frequent use of pesticides has significant harmful effects on soil ecosystems. In Romania, studies conducted in regions with intensive agriculture have shown a reduction in the diversity of beneficial bacteria and fungi, with an impact on nitrogen fixation and nutrient recycling processes. Also, pesticides such as organophosphorus persist in the soil for more than a year, increasing the risk of contamination. Restoring soil biodiversity is also an important measure in combating soil pollution. Healthy soils are characterised by high biodiversity, which helps to maintain an ecological balance and ensure vital soil functions such as the decomposition of organic matter and the recycling of nutrients. Some recent research has highlighted the importance of restoring soil microorganisms, especially bacteria and fungi that are essential for soil fertility (Pereira et al., 2021). By using more environmentally friendly farming practices and reducing the use of

pesticides and chemical fertilisers, you can help restore soil biodiversity and increase its capacity to self-regenerate.

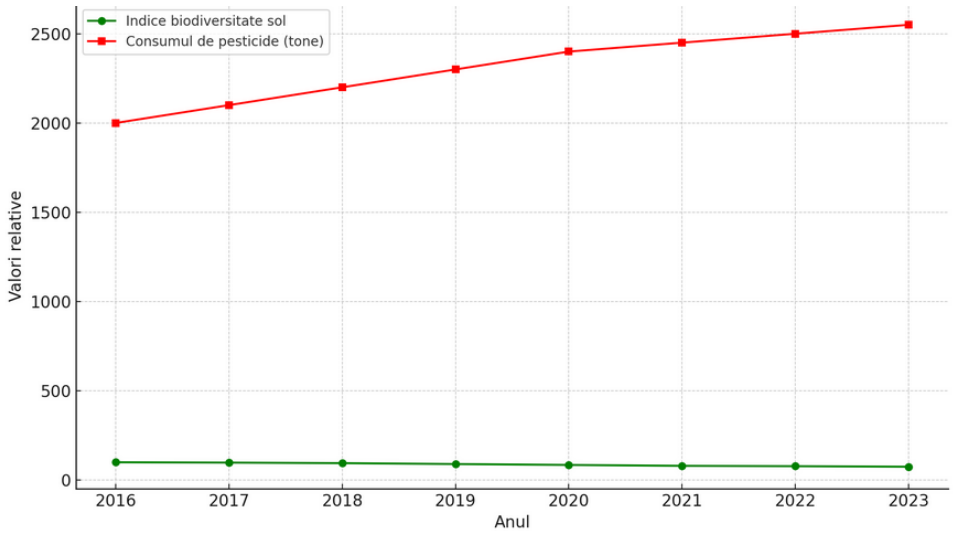

Fig.3. Evolution of soil biodiversity and pesticide consumption

Industrial waste, hazardous waste, and chemicals used in production processes can contaminate soils, affecting not only the health of the environment, but also nearby communities. It is essential for industry to adopt more responsible practices in waste management and to implement polluted soil cleaning technologies, such as bioremediation, which use microorganisms to break down toxic substances in the soil (Müller et al., 2019). These measures contribute to the recovery of contaminated soils and the prevention of further pollution.

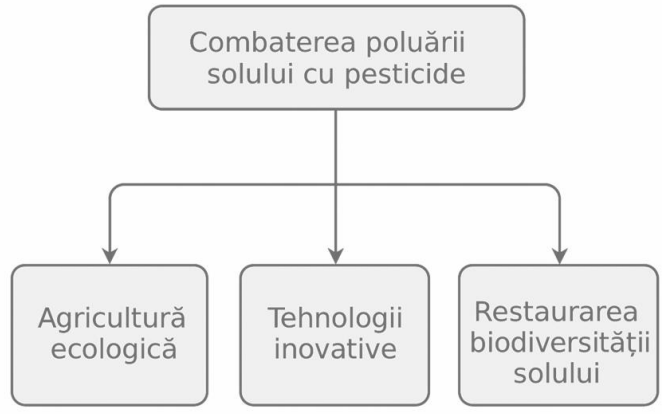

Fig.4 Evolution of soil biodiversity and pesticide consumption

Figure 4 shows an inversely proportional trend between pesticide use and soil biodiversity. As pesticide consumption increased steadily between 2016 and 2023, soil biodiversity decreased significantly. This phenomenon highlights the negative impact of intensive agricultural practices on soil ecosystems and highlights the need to transition to sustainable methods, such as organic farming, precision farming and bioremediation, in order to protect soil fertility and environmental health.

4. CONCLUSIONS

The need for sustainable measures to combat soil pollution caused by the intensive use of pesticides and other chemicals in agriculture, highlights the role of organic farming practices – such as the use of organic fertilisers, natural pest control, crop rotation and composting – in reducing the negative impact on soil fertility and biodiversity. Precision agriculture, through the controlled and monitored application of chemicals, further contributes to reducing the polluting effects.

We also highlight the importance of implementing strict government policies and regulations that limit the use of pesticides and promote sustainable alternatives. Such measures must be accompanied by continuous monitoring of the state of the soil and the environment. Another essential direction is the restoration of already degraded soils, through techniques such as bioremediation and erosion control, in order to restore their ecological functions.

At the same time, the role of education and public awareness – especially farmers and consumers – in reducing soil pollution, by informing about the risks associated with pesticides and promoting environmentally friendly alternatives. In conclusion, soil protection requires an integrated approach, combining technological innovation, political intervention, good agricultural practices and environmental education, in order to ensure a sustainable and healthy environment.

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