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Monitoring, Risk Assessment and Safety Assurance in the Use of Pesticides in Agriculture

The use of pesticides in modern agriculture represents a complex multidimensional problem, involving the search for a balance between ensuring food security and minimizing adverse impacts on human health and the environment. On one hand, agrochemicals play a significant economic role in supporting the stability of agricultural production; on the other, they pose substantial risks that manifest at various levels – from individual farms to global ecosystems. It is underscored that further research can provide a valuable contribution to the formation of effective state policy aimed at gradually reducing dependence on pesticides. A promising direction includes evaluating the effectiveness of state support for farmers, developing practical guidelines for the safe use of agrochemicals, establishing systems for regular monitoring and data analytics to inform decision-making, as well as creating networks for interaction and experience exchange among farms.
agricultural engineering, pesticide, monitoring, risk assessment, safety assurance

Problem Statement. The use of pesticides in modern agriculture represents a complex systemic dilemma involving the search for balance between ensuring food security and minimizing negative impacts on human health and the environment. The global scale of pesticide application is considerable: worldwide consumption amounts to approximately two million tons of active substances per year, with projections reaching up to 3.5 million tons in the near future [1]. This process not only highlights the economic importance of pesticides for agriculture but also reveals a wide range of adverse consequences that manifest at various levels – from individual farms to international ecosystems.

The main mechanism of pesticide dispersion relative to their application site is drift, which can transport chemical substances over hundreds of meters, and in some cases – even thousands of kilometers [2]. This creates a significant ecological risk, as drifting pesticides affect non-target species, reduce biodiversity, and disrupt ecosystem processes.

Analysis of Recent Research and Publications. One of the most striking environmental consequences of pesticide use is the contamination of surface waters. Long-term studies indicate that changes in pesticide application practices and hydrological conditions are the dominant factors influencing surface water pollution. In the United States, for example, a USGS study found that more than 88 % of water samples from 72 monitoring sites contained at least five different pesticides simultaneously, while over 90 % of monitoring points contained pesticide degradation products [3]. Substances such as atrazine, deethylatrazine, carbaryl, and metolachlor are among the most commonly detected. The contamination can be persistent in nature.

The impact of pesticides on biodiversity is extensive, affecting both plant and animal populations. Herbicide drift, particularly from synthetic auxins such as 2,4-D and dicamba, poses a direct threat to sensitive specialty crops such as grapes, where yield reduction, vine damage, and winter hardiness disruption can occur. Ecosystems located near agricultural lands, such as mountain rivers, may suffer from chronic contamination. Moreover, a meta-analysis of 54 studies confirmed that pesticides generally reduce the abundance and diversity of soil fauna, with broad-spectrum products and insecticides being the most harmful. Fungicides and herbicides also exert significant negative effects on the activity of microorganisms that play a key role in nitrification, particularly ammonia-oxidizing archaea and bacteria [4].

The effects of pesticides on human health are among the most extensively studied and well-documented aspects of their use. Chronic exposure, even at low concentrations, is associated with an increased risk of a wide range of diseases. Scientific consensus indicates a link between pesticide exposure and various cancers, including leukemia, lymphoma, lung cancer, prostate cancer, and breast cancer [5]. A comprehensive population-based study conducted in the United States demonstrated that the level of pesticide use correlates with a higher risk of all cancer types, and for certain types – such as leukemia and lymphoma – the association is even stronger than that with smoking.

Particularly vulnerable groups include agricultural workers, who are exposed to the highest levels of pesticides [6]. However, even rural residents not directly involved in agricultural activities face risks through the consumption of contaminated food and water, as well as through pesticide drift. Neurological disorders, such as Parkinson’s disease, are also strongly associated with exposure to organophosphate pesticides and other compounds. Pesticides can act as endocrine disruptors, affecting hormonal balance, reproductive function, and fetal development [6]. For instance, a prospective cohort study in France found a correlation between prior exposure to atrazine and adverse pregnancy outcomes.

A meta-analysis of 145 studies revealed that workers exposed to pesticides exhibit significantly higher levels of genetic damage, confirming their elevated carcinogenic and mutagenic potential. Moreover, evidence links pesticide exposure to an increased risk of respiratory diseases such as asthma [6]. These findings underscore the importance of a comprehensive risk assessment approach that accounts not only for individual substances but also for mixtures (“cocktails”) of pesticides to which people are realistically exposed [5].

Table 1 – Global and Local Dimensions of Pesticide Risk: Environmental and Human Health Impacts

Aspect	Global impact
Environmental consequences	Contamination of surface water, soil, and air; loss of biodiversity (plants, insects, birds, amphibians); disruption of ecosystem processes
Health effects (directly on workers)	Oncological diseases (leukemia, lymphomas), neurological disorders (Parkinson’s disease), endocrine disorders, reproductive dysfunction
Health effects (population)	Risk from consumption of contaminated food and water; exposure through pesticide drift into residential areas; association with asthma and other respiratory diseases
Major pollutants	Atrazine, metolachlor, dicamba, 2,4-D, glyphosate, organophosphates, neonicotinoids

Source: developed by the author

Results and discussions. The situation regarding the monitoring, risk assessment, and safety assurance of pesticide use in Ukraine is both unique and complex, shaped by the synergistic effect of several interrelated factors. The first and most apparent factor is the scale of agrochemical use. Ukraine is among the largest consumers of pesticides in Europe, with approximately 100,000 tons used annually. Such an enormous “chemical load” places considerable pressure on ecosystems and poses increased risks to public health.

This is confirmed by monitoring results showing exceedances of the maximum allowable concentrations (MAC) of pesticides in the waters of the Dnipro and Siverskyi Donets rivers [7]. The prevalence of pesticide use is uneven, being concentrated mainly in the southern and central regions of the country. These regions also exhibit significantly higher cancer morbidity rates, which researchers associate with intensive agricultural chemicalization [8].

The mechanism underlying this link lies in the fact that agricultural workers – especially those employed on small-scale farms lacking effective control systems – often fail to follow safety regulations and do not use personal protective equipment, resulting in high levels of exposure.

Another critically important factor is the issue of counterfeit pesticides. Estimates indicate that up to one-third of the pesticide market in Ukraine consists of unregistered, hazardous, and often uncontrolled products. These substances may be either effective or conversely, harmful to crops, but the main threat lies in the fact that their composition, concentration, and toxicity are unknown, leading to long-term contamination of soil and water resources. The war has further complicated the situation, as large stocks of agrochemicals are stored in territories located within active combat zones (such as Dnipropetrovsk, Donetsk, and Chernihiv regions, among others), creating a potential environmental catastrophe [9]. The lack of functional facilities for the safe disposal of confiscated or expired chemicals represents an additional threat.

It should be noted that Ukraine's regulatory system, particularly regarding risk assessment and safety assurance in the use of pesticides in agriculture, is in a state of transition from the Soviet model to the European one. This transitional phase has led to a legal vacuum and considerable instability. The key authority responsible for pesticide registration and control is the Ministry of Ecology and Natural Resources.

The registration process consists of four stages: inclusion in the testing schedule, pre-registration studies, expert evaluation of the results, and the issuance of a state registration certificate. To obtain registration, applicants must submit detailed information about the product, toxicological and ecotoxicological study reports, and a methodology for determining residual quantities.

The maximum residue levels (MRLs) are established by the Ministry of Health of Ukraine and the State Service of Ukraine on Food Safety and Consumer Protection. However, the system still bears the legacy of the past, as many regulations and standards (GOSTs) remain outdated and inconsistent with modern requirements. As a result, Ukraine still permits the use of substances that are banned in the European Union, directly increasing risks to human health and ecosystems.

For instance, thiacloprid, a pesticide hazardous to bees, is widely used in Ukraine and classified as "moderately hazardous" to pollinators – in stark contrast to its strict prohibition within the EU. The process of harmonization with the European Union is the primary driver for reforming Ukraine's regulatory framework. Ukraine is required to align its legislation with key documents such as Directive 2009/128/EC of the European Parliament and of the Council on the Sustainable Use of Pesticides (SUD) and Regulation (EC) No. 1107/2009 of the European Parliament and of the Council.

Harmonization of Ukrainian and EU legislation necessitates the implementation of measures such as the development of a National Action Plan, mandatory operator certification, monitoring of equipment technical condition, and the adoption of Integrated Pest Management (IPM) principles [10]. However, as demonstrated by the experience of EU member states, the mere adoption of legislation does not guarantee its successful implementation.

Ukrainian hygienic assessments conducted by the F.F. Erisman Institute of Occupational Hygiene and Medical Toxicology have shown that when standards are followed and personal protective equipment (PPE) is used, the risks to workers remain within acceptable limits [11, 12]. Nevertheless, practical studies indicate persistent hazards: low awareness of risks among agricultural workers, inadequate or insufficient protective equipment, and unsafe handling practices with chemical agents. This gap between theoretical compliance and actual field conditions represents a critically important finding, underscoring the need to strengthen supervision and expand on-site training and education programs.

Table 2 – Systematic analysis of the regulatory framework and practices of pesticide use in Ukraine compared to the EU

Regulatory aspect	Ukraine	European Union
Key regulator	Ministry of Environmental Protection and Natural Resources of Ukraine	European Food Safety Authority, EFSA
Main directive	Directive 2009/128/EC (SUD) (in process of harmonization)	Directive 2009/128/EC (SUD) (implemented)
Supply Regulation	Regulation (EC) No. 1107/2009 (in process of harmonization)	Regulation (EC) No. 1107/2009 (implemented)
Maximum residues (MRLs)	Established by the Ministry of Health of Ukraine and the State Service of Ukraine on Food Safety and Consumer Protection	Established by EFSA, is a single level for all countries
Counterfeiting problem	Serious problem (up to a third of the market)	Controlled through the "single window" system and customs control
Monitoring status	Limited, mainly for food products	Integrated monitoring of surface waters, soils, biota
Banned substances	Many substances banned in the EU are allowed to be used (e.g. thiacloprid)	225 active substances banned, 274 not approved

Source: developed by the author

A comparative analysis of the regulatory frameworks of Ukraine and the European Union in the field of pesticide application reveals significant discrepancies that determine differing levels of risk to human health and the environment. The EU system is comprehensive, multi-level, and structured to ensure a high degree of protection. It is built upon two key legislative acts: Regulation (EC) No. 1107/2009, which establishes the procedure for the approval of active substances, and Directive 2009/128/EC (SUD), which provides the overarching legislative framework for the sustainable use of pesticides in each Member State [13].

Regulation (EC) No. 1107/2009 requires compliance with high standards for the protection of human health and the environment, including a detailed assessment of the toxicological, ecotoxicological, and environmental properties of substances. The approval of an active substance is a mandatory first step – without such approval, no pesticide can be placed on the EU market. The EU maintains a unified list of banned and non-approved substances, which currently includes 225 banned and 274 non-approved active substances, ensuring a uniform level of protection across all 27 Member States.

Directive 2009/128/EC (SUD), in turn, serves as a local-level instrument that obliges each Member State to develop and implement a National Action Plan aimed at reducing the risks and adverse impacts associated with pesticide use [14]. This plan must contain quantitative targets, measures, and timelines, and include key components such as:

– mandatory certification and training of professional users,
– regular inspection and calibration of equipment,
– prohibition of aerial pesticide spraying (except in exceptional cases),
– establishment of buffer zones around water bodies, and
– bans on pesticide use in designated sensitive areas (e.g., parks, schools, hospitals) [14].

To monitor progress, the EU employs Harmonised Risk Indicators (HRIs), which are based on sales data of active substances and allow for trend analysis of pesticide use across the Union. However, even with these sophisticated instruments in place, the overall effectiveness of the implementation of Directive 2009/128/EC (SUD) within the EU is considered only “moderate”.

Ukraine, in the process of accession to the EU, is striving to harmonize its national legislation with key EU documents, such as Regulation (EC) No. 1107/2009 and Directive 2009/128/EC (PPP). A national action plan is already being developed, and some of its provisions have been integrated into existing legislation, such as the Law of Ukraine “On State Regulation in the Field of Plant Protection”. However, unlike the EU, where these rules are applied equally in all Member States, Ukraine is still in the process of gradual adaptation and amendment.

One of the most striking differences lies in pesticide ban policies. The EU maintains a unified list of substances prohibited for use throughout all 27 Member States. Ukraine, by contrast, still allows the use of thiacloprid (Biscaya 240 OD), a neonicotinoid classified as moderately hazardous to bees – in contrast to the EU’s much stricter bans. This means that if Ukraine were part of the EU, the use of such a pesticide near residential areas would violate three aspects of EU legislation: the ban on aerial spraying, the restriction on pesticide use near populated areas, and the prohibition on using banned active substances.

This single regulatory difference leads to a paradoxical situation: Ukraine has become one of the largest exporters of pesticides banned in the EU, resulting in a scenario where domestically produced agricultural goods may contain residues of substances prohibited under European standards.

In terms of monitoring, the European Union operates comprehensive and systematic programs that include the control of pesticide residues in water, soil, and food products [15]. The results of these monitoring programs are publicly available and serve as a basis for risk assessment and regulatory control. Ukraine has also established a monitoring system covering both agricultural products and environmental components such as soil and water resources [16]. However, its effectiveness and completeness remain less transparent and less systematically documented [17].

A key issue in Ukraine is the limited number of accredited laboratories – only one out of five interregional laboratories currently holds ISO 17025 accreditation. This shortfall restricts both the reliability of analytical results and their international recognition. Thus, although Ukraine is progressing in the right direction by harmonizing its legislation with EU standards, persistent discrepancies in regulatory standards, pesticide ban policies, and monitoring effectiveness continue to create a substantially higher level of environmental and health risk compared with the European Union.

Conclusions. Despite the substantial volume of scientific data concerning the adverse consequences of pesticide use, there exists a series of critically important knowledge gaps that constrain the effectiveness of monitoring, risk assessment, and the development of regulatory policies. One of the most significant gaps is the underestimation of the multi-chemical effect, or the so-called "cocktail effect". Typically, risk assessments and regulatory acts focus on the impact of individual active substances, establishing maximum residue levels (MRLs) and maximum permissible concentrations (MPCs) for them. However, in practice, humans and ecosystems are simultaneously exposed to mixtures of numerous pesticides applied to a single field or infiltrating the environment from various sources. The synergistic toxicity of such mixtures remains poorly studied, although it represents an evident source of hazard. For instance, research has demonstrated that pesticide mixtures can exert a stronger phytotoxic effect on non-target plants than individual components. Similarly, the impact of mixtures on human health, particularly on the endocrine system and reproductive function, receives scant attention. Research is essential to model and measure real-world combinations of pesticides observed in the environment in order to better evaluate cumulative risk.

Secondly, there exists a significant gap concerning the completeness and accuracy of monitoring in Ukraine and many other countries. The available data are often limited and focused solely on food products or selected monitoring points. There is no systematic, ongoing, and representative monitoring of pesticide concentrations in air, soils, and surface waters across all regions, which hinders the accurate assessment of environmental impact and risks to public health, particularly in rural areas. The absence of such data complicates the development of effective monitoring and regulatory measures. For example, in Ukraine, data exist on the pollution of the Dnipro and Siverskyi Donets rivers, but there are no systematic data regarding air pollution, which is one of the primary pathways of exposure for the population. The development and implementation of a comprehensive monitoring program, similar to those in Europe, is a priority task for obtaining reliable data.

Thirdly, the long-term health consequences for humans from exposure to low concentrations of pesticides are exceedingly complex to study. Although strong correlations exist between pesticide use and certain diseases, including cancer, establishing causality at the population level is a challenging endeavor. This is associated with the multifactorial nature of many illnesses, the high cost of long-term studies, and the influence of other factors such as genetics, dietary habits, and additional chemical substances. In the case of Ukraine, research establishing a link between pesticide use and the incidence of oncological diseases is rare and often based on correlations that cannot prove direct causation. The majority of studies are conducted in the USA and Europe, while data for Ukraine are limited. Long-term prospective cohort studies under Ukrainian conditions are necessary, which would measure exposure levels (through analysis of biomaterials, for example, urine or blood) and track disease development in the subjects.

Fourthly, in practice, Integrated Pest Management (IPM) is often implemented formally, rather than as a genuine means of reducing chemical usage. IPM serves as an official recommendation in Ukraine and the EU, yet its actual effectiveness depends on numerous factors, including technologies, methods, and socio-economic incentives. It is essential to investigate which specific technologies, methods, and socio-economic incentives prove most effective for disseminating IPM under Ukrainian conditions. This may encompass evaluating the impact of state support, developing practical guidelines for farmers, implementing monitoring systems and data analysis for decision-making, and establishing support networks and experience-sharing among farmers. Such research could yield valuable data for formulating effective policies directed toward the gradual reduction of pesticide dependency.

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Моніторинг, оцінка ризиків та забезпечення безпеки використання пестицидів у сільському господарстві

Використання пестицидів у сучасному сільському господарстві становить складну багатовимірну проблему, що полягає у пошуку балансу між забезпеченням продовольчої безпеки та мінімізацією негативного впливу на здоров'я людей та стан довкілля. З одного боку, агрохімікати відіграють важливу економічну роль, підтримуючи стабільність сільськогосподарського виробництва, з іншого, вони створюють значні ризики, що проявляються на різних рівнях – від окремих ферм до глобальних екосистем. Особливо небезпечним є дрейф пестицидів, який завдає шкоди нецільовим видам, знижує рівень біорізноманіття та порушує природні екосистемні процеси.

На основі аналізу наукових досліджень окреслено спектр негативних впливів пестицидів: забруднення поверхневих вод, яке має масштабні екологічні наслідки; негативний вплив на флору та фауну; ризики для здоров'я людини – питання, що є найбільш дослідженим науковою спільнотою. Зазначено, що особливу вразливість демонструють працівники аграрного сектору, які зазнають найвищого рівня експозиції. Підкреслено важливість комплексної оцінки ризиків, що враховує не лише окремі хімічні речовини, а й комбіновану (коктейльну) дію сумішей пестицидів, які є типовою реальністю експозиції.

У роботі проаналізовано масштаби використання агрохімікатів в Україні – однієї з провідних країн Європи за рівнем споживання пестицидів. Розглянуто проблему поширення контрафактних препаратів, а також сучасний стан регуляторної системи, що перебуває у фазі переходу від застарілої моделі до європейських підходів. Така ситуація породжує нормативну невизначеність та непослідовність у державній політиці контролю і оцінки ризиків від застосування пестицидів.

Незважаючи на значний обсяг наукових даних, виявлено низку критично важливих прогалин у знаннях, які обмежують ефективність моніторингу, оцінювання ризиків і формування регуляторної політики, зокрема: недооцінювання мульти-хімічного ефекту, тобто сумарної дії «коктейлю» пестицидів; нестача повноти та точності даних моніторингу, характерна для України та багатьох інших країн; складність вивчення довгострокових наслідків низькорівневої експозиції для здоров'я населення; формальність впровадження інтегрованого управління шкідниками (ІМП), ефективність якого залежить від технологічної забезпеченості, наявних методів та економічних стимулів у вітчизняних умовах.

Підкреслено, що подальші дослідження здатні забезпечити цінний внесок у формування ефективної державної політики, спрямованої на поступове зменшення залежності від пестицидів. Перспективним напрямом є оцінка результативності державної підтримки фермерів, розробка практичних настанов з безпечного використання агрохімікатів, створення систем регулярного моніторингу та аналітики даних для прийняття рішень, а також формування мереж взаємодії та обміну досвідом між господарствами.

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