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Operationalizing the Sustainable Fertilizer Management Global Initiative at National Level: A Conceptual Framework

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Abstract. Humanity is tasked with finding a balance between the need to increase the amount of food and the negative socio-environmental and economic consequences of the irrational use of fertilisers. At the global level, a number of initiatives have been launched to consolidate countries' efforts to address this problem. However, existing national fertiliser management systems and policies are characterised by insufficient consistency and low efficiency. This study aims to formulate a conceptual framework for developing a national sustainable fertiliser management system that meets the principles set out in existing global initiatives. Through the generalisation of the content of existing intergovernmental initiatives on sustainable fertiliser management, the subject composition was formulated, and estimates of the relationship between fertiliser application and public health (through the number of cancer diseases) through the use of regression analysis methods, assessment of economic damage from irrational fertilisation served as a substantiation (illustration of the importance of highlighting) of components covering: awareness, knowledge, tools. The national sustainable fertiliser management system is considered three-dimensional integrity containing the following interrelated components: government, fertiliser production and supply industries, and users. The functioning of this system is seen as a continuous process of raising awareness, generating and transferring knowledge, selecting and applying appropriate tools, and improving fertiliser application practices in accordance with the principles of sustainable development, with the leading role of government. The process of raising awareness of all actors of the system about the problem of irrational fertilisation is proposed to be considered in a broader context – through the demonstration of negative consequences not only for the environment (soil condition), but also from the standpoint of the impact on public health and related consequences – through the assessment of economic damage caused by pollution and consumption of food containing harmful substances. The main principles of interaction of subjects in this system should be the following: professionalism, transparency, information support, etc. Special attention should be paid to the formulation of a set of strategic goals that would lay the foundation for the development of control and evaluation procedures, a system for monitoring and reviewing mechanisms for economic incentives for fertiliser use, considering the social and environmental aspects of fertiliser use

Keywords: sustainable fertiliser management, national fertiliser policy, awareness, knowledge transfer, safe fertiliser, food security

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INTRODUCTION

Food security — provision of the physical and economic availability of food for present and future generations — is the biggest challenge of modern development. Due to the need to increase food production, the intensification of agriculture seems to be the only way to achieve food security goals, with the use of fertilisers as an integral part. According to some estimates, the expected population growth in the coming decades will increase the burden on agricultural production by 50-80%, which will lead to an increase in the sector's dependence on fertiliser use (Yang *et al*., 2017). Intensive agricultural practices, which allow increasing or reducing the cost of food production, simultaneously threaten the balance of agroecological systems (Pandey & Diwan, 2018) and lead to increased pollution of agricultural resources, a decrease in the quality of agricultural products and food. Thus, soil health and sustainable fertiliser management should be an important part of the investigation of environmental aspects of food security (Kolesnyk *et al*., 2018; Ramankutty *et al*., 2018). The most difficult part is finding a compromise between producing enough food at affordable prices through fertiliser application and the associated negative impact of agriculture on the environment, ecosystems, and public health. The global fertiliser management initiative, launched in recent years, is a way to address this problem.

The purpose of the study is to define the main conceptual components and principles of forming a comprehensive system for ensuring sustainable fertiliser management at the national level.

LITERATURE REVIEW

Despite the fact that the problems of soil fertility as a component of achieving food security, the problems of the impact of anthropogenic activities (agricultural production) on the components of the environment and the state of soils are not new, these issues have recently remained behind the scenes of global actions towards achieving the goals of sustainable human development. A number of global initiatives have been launched only since 2016, aimed at drawing public attention to the problems of soil health, nutrients, and fertilisers. Thus, in September 2016, at the 25th session of the Committee on Agriculture (COAG), a call was made to the Food and Agriculture Organisation of the United Nations (FAO) regarding the need for more intensive action toward ensuring food safety, in particular, in terms of the safe use of fertilisers and pesticides (FAO, 2016). Within the framework of the Global Soil Partnership (GSP) initiative, voluntary Guidelines for Sustainable Soil Management were presented together with the FAO, aimed at addressing the problems of nutrient imbalances and soil pollution caused, among other things, by unstable fertilisation (excessive, insufficient, or polluting). (FAO, 2017). The result of a long multilateral process of discussion and agreement, the search for compromise solutions on the issues raised in these documents was the release of an International Code of Conduct for the Sustainable Use and Management of Fertilisers (FAO, 2019), containing a set of voluntary standards for government, industry, researchers, users, and other stakeholders in the use and management of fertilisers, the implementation of which should ensure sustainable agricultural production and food security in terms of nutrient management (FAO, 2019). Ultimately, under the auspices of the United Nations in 2019, Sri Lanka approved the Colombo Declaration, which sets the task for the signatories to develop a Roadmap for Action on Sustainable Nitrogen Management 2020-2022, considering it as one of the mechanisms of interconnection and coordination for better and more sustainable nitrogen management (Colombo Declaration on Sustainable Nitrogen Management, 2019). The focus on nitrogen emissions, to a certain extent, is a consequence of active global actions in the context of climate change, but similar initiatives are also being developed for sustainable management of phosphorus (Brownlie *et al*., 2021; Garske & Ekardt, 2021) and other nutrients. In the summary of the contents of the UN Declaration and Initiative on International Nitrogen Management System (INMS), the task set is to halve nitrogen emissions (Sutton *et al*., 2019; UNEP, 2019) — is, first of all, critical from the standpoint of countering climate change, ensuring food security, and ecosystem health (Pandey & Diwan, 2017; Yin *et al*., 2020). And secondly, it can only be solved within the framework of a comprehensive system of actions for sustainable management of nutrients and fertilisers in general, because the efficiency of using one element is inseparable from managing a complex of nutrients.

Thus, a certain conceptual framework has now been formed at the global level and a global discussion and joint actions have been initiated to address the problems associated with soil pollution, and one of the reasons for this is the use of fertilisers. At the same time, mechanisms for operationalising these global decisions at the national (and, accordingly, regional and local) levels need to be developed.

Commenting on the content of the Code (FAO, 2019) and Declarations (Colombo Declaration on Sustainable Nitrogen Management, 2019) the Code establishes the complexity and multi-level system of sustainable fertiliser management, the need to involve various groups of stakeholders in this process, among which government structures play a decisive role. A comprehensive system of sustainable fertiliser management should contain various functional components: assessment, analysis, justification, knowledge, information, timely monitoring and control, support for implementation, etc. (FAO, 2019). Proper management and use of fertilisers should cover operations at all levels of the value chain: responsible production, storage, transportation, use to improve plant growth or other parameters while maintaining or improving the health of fertilisers and minimising negative environmental impact (FAO, 2019). The code of conduct covers the following areas: soil fertility and plant nutrition; fertiliser use and management; nutrient reuse and recycling; composition, restriction, and testing; access, distribution and labelling; information,

consultation, and dissemination of information on sustainable fertiliser management; implementation of the code (all governments, supported by FAO and other organisations, are expected to be involved in this process to the fullest extent possible, although this code is also voluntary). And in all areas, the role of the government component is the most significant, consisting mainly in the development of policies that promote sustainable fertiliser management (FAO, 2019).

According to the approved Declaration (Colombo Declaration on Sustainable Nitrogen Management, 2019), governments are called upon, as far as possible: to develop and implement appropriate policies for sustainable nitrogen management; to develop roadmaps in accordance with these policies to halve nitrogen emissions by 2030; to assess the quantitative and qualitative apsects of nitrogen management policies and conditions; to encourage innovation for nitrogen reuse in accordance with the principles of the circular economy; to encourage populations and best practices for better nitrogen management; to develop partnerships and report on progress in this area (Colombo Declaration on Sustainable Nitrogen Management, 2019).

Many technological solutions have already been developed to improve fertiliser management practices and enhance fertiliser efficiency (Srinivasarao, 2021), which cover, in particular: the use of organic substances and biofertilisers, the combination of chemical fertilisers with organic ones, crop rotation, waste management, various ploughing practices (tillage) (Naher *et al*., 2019; Young *et al*., 2021) and even digital technology support solutions (Golicz *et al*., 2021; Hou *et al*., 2020). At the same time, the level of implementation of these technologies is insufficient (Melnyk *et al*., 2021) and it does not solve the problem of soil health errors, which is global in nature. The reason for this is the difficulty of finding solutions that would ensure a balance of individual economic interests of commodity producers with the interests of society and illustrate the need and advantages of such a balance.

Noting the growing global focus on sustainable nutrient and fertiliser management as its component (Baritz *et al*., 2018; Brownlie *et al*., 2021), researchers point out, at the same time, the problem of transforming global solutions and attracting attention at the level of national politicians, and therefore users (Baritz *et al*., 2018), lack of nationally adapted solutions, unsystematic and, as a result, low effectiveness of national policies in this area, even in developed countries, in particular, in the EU (Garske *et al*., 2020; Helming *et al*., 2018), Canada (Kröbel *et al*., 2021), etc. An explanation for this may be the lack of information on the effects of fertiliser use in terms of human health and economic losses, in particular, relevant national estimates. Thus, many results of assessments of the negative effects of fertiliser use are currently available. For example, it is known and documented that nitrogen fertilisers cause the formation of "dead zones" in the Midwest of the United States, bring about EUR 70-320 billion annually in economic losses in Europe, cause environmental problems in China and India (Pandey & Diwan, 2017), and is one of the reasons of cancer diseases (Yin *et al*., 2020). Researchers assess the state of agricultural production and environmental consequences and try to form an integrated framework for assessing the risk of food hazard and agroecological risk use indicators: the state of the food system (crops grown), losses due to natural hazards; the ratio of supply/demand mismatch and the associated risk of food hazard, the index of environmental load on water resources and the associated agroecological risk (Qi *et al*., 2018). And if the results of assessments of the impact of fertiliser use on soils are regularly published and make society talk more and more about soil health, then the study on the impact of fertilisers on public health began in the mid-1930s and peaked in the 1970s and 1980s (Senesil *et al*., 1999). The main subject of attention was the connection between the practices of fertiliser use and the spread of cancer (Senesil *et al*., 1999), but now the impact of agriculture on public health is being considered in relation to the use of pesticides (Bonner & Alavanja, 2017; Budzinski & Couderchet, 2018; Iriti & Vitalini, 2020), although, the existing strict rules allow mitigating the relevant risks (Iriti & Vitalini, 2020). Since the 1990s, research on the health effects of fertilisers has been declining, mainly due to a shift in research funding priorities towards climate change (Senesil *et al*., 1999). It is equally important that negative environmental consequences should be transformed into clear economic indicators, but today such studies are not enough. For example, Yang *et al.* (Yang *et al*., 2017) found that in China, health care costs caused by fertilisation account for about 0.5% of agricultural output, and interregional fluctuations in the deterioration of health caused by fertilisation also affect the assessment of economic losses (Yang *et al*., 2017).

China's experience in implementing a strategy to maximise the yield of agricultural products while reducing the use of fertilisers is quite successful. The corresponding policy was established in 2004 through a number of political innovations, which, among other things, contributed to the implementation of innovative technologies in production. The components of China's success in this area are: legislative regulation of the need for soil testing and the development of recommendations for fertilisation based on the results of analysis within the framework of the soil testing and fertiliser recommendations STFR initiative and Zero Increase Action Plan (This facilitates a 50% reduction in nitrogen and phosphorus use and 100% nutrient efficiency, without reducing yields (Jiao *et al*., 2018) and already in 2019, all provinces reported on the achieved zero level of increase in the amount of fertilisers (Yu *et al*., 2020); development and implementation of a package of flexible economic tools (depending on the socio-economic conditions of the region) that encourage producers to analyse soils, introduce recommendations for fertilisers, use organic substances to increase soil fertility; ensure the coordinated work of all components of the fertiliser management chain; support for scientific developments and their distribution (Jiao *et al*., 2018).

In particular, to solve the problem of knowledge transfer, a network of advisory structures Science and Technology Backyards (STB) was created in 2009 in different ecological zones, which "brought together" science and practitioners, and the result of its work was an increase in technology implementation by 80%, an increase in yields by 20%, and a reduction in environmental costs by 20% (Jiao *et al*., 2018). At the same time, the problem of raising awareness and transferring knowledge in the field of sustainable fertiliser management still remains one of the most urgent and not fully solved (Jiao *et al*., 2018; Yu *et al*., 2020).

Existing studies on the construction and development of national incentive systems for sustainable fertiliser management focuses mainly on a separate component (tools) of such a system, in particular: impact assessments (Helming *et al*., 2018) as a means of raising awareness and meeting the goals of society; assessing the state of soils and developing appropriate indicators that can serve as a basis for informing (Hou *et al*., 2020; Tingyu *et al*., 2020) and decision making (Kik *et al*., 2021); identifying participants and developing targeted strategies (Kanter *et al*., 2020); consulting and knowledge dissemination practices (Baritz *et al*., 2018; Hou *et al*., 2020) economic instruments (quotas and trade in emissions of substances – Cap-and-trade schemes; subsidies; taxation of the content of pollutants in fertilisers) (Garske & Ekardt, 2021; Scholz & Geissler, 2018); regulation of the size of animal husbandry (Garske & Ekardt, 2021) development of methodology and rationing (limiting) the amount of fertilisers applied for each zone, taking into account natural and climatic factors (Jiang *et al*., 2020; Lemaire *et al*., 2021; Wang *et al*., 2019); development and use of programmes to support solutions in the field of fertiliser use (Villalobos *et al*., 2020). Special attention is paid to the mechanisms of knowledge dissemination, consulting (Mills e al., 2020; Pan & Zhang, 2018), and investigation of factors that influence individual decisions on the use and management of fertilisers (Andan *et al*., 2019; Hu *et al*., 2019; Rahman & Zhang, 2018).

The available findings reveal certain aspects of building a comprehensive system for stimulating sustainable fertiliser management practices at the national (and sub-national) level, but there is still an urgent need to develop more systematic integrated government concepts that would eliminate the transition of the problem from one area to another and provide optimal solutions at the system-wide level (Garske & Ekardt, 2021; Garske *et al*., 2020), based on a clear understanding of the problem, and above all, through an understanding of the consequences of irrational use of fertilisers.

MATERIALS AND METHODS

Highlighting the main participants in the national system of sustainable fertiliser management and the investigation of the content of relationships between them was carried out through the analysis and generalisation of the provisions of international and intergovernmental initiatives in the field of sustainable fertiliser management. To substantiate the component components of the fertiliser management system and their content, the relationship between fertiliser application levels and public health (cancer incidence) was evaluated using regression analysis methods. The study was carried out using the built-in functions of the MS Office Excel software suite. The data from the state statistics service of Ukraine (collections "Health care institutions and morbidity of the population of Ukraine" and "Application of mineral and organic fertilisers for crops") for 2010-2020 was used to build a regression model based on average data for Ukraine.

In the model used, the number of oncological diseases registered in medical institutions at the end of the year per 100 thousand population cases is selected as a dependent variable (y); as a regressor (X) – the amount of mineral fertilisers in nutrients in kg per 1 ha of sown area, kg/ha.

To investigate the spatial variations in fertiliser exposure and cancer incidence, administrative districts are grouped by natural and geographical zones. Thus, the Polissya zone includes Volynska, Zhytomyrska, Rivnenska, Chernihivska oblasts; forest-steppe – Kyivska, Vinnytska, Poltavska, Sumska, Ternopilska, Khmelnytska, Kharkivska, Cherkaska oblasts; steppe – Dnipropetrovska, Zaporizka, Kirovohradska, Mykolaivska, Odeska, and Khersonska oblasts; the Carpathian Mountain zone includes Zakarpatska, Ivano-Frankivska, Lvivska, and Chernivetska oblasts. Donetska and Luhanska oblasts were not analysed due to incomplete information caused by the military conflict.

To illustrate the economic impact of fertilisation practices, economic health losses from consumption of contaminated food for 2020 for different natural and geographical zones were estimated, according to regional estimates of average annual environmental damage from pollution (air, water resources) for 2001-2009 (Sotnyk & Kulyk, 2014; Sotnyk & Kyrychok, 2012) and data on the structure of environmental damage (Karintseva, 2018; Rsarenko *et al*.,2002).

RESULTS AND DISCUSSION

Summarising the provisions of the Code of conduct in the field of sustainable fertiliser management (FAO, 2019), and the results of a previous study, the national system for ensuring sustainable fertiliser management can be presented as integrity formed by three basic components: the government; the industry for developing, manufacturing, testing, and bringing fertilisers to the end-user (including research organisations, institutes, and universities); fertiliser users. At the same time, providing sustainable use and management of fertilisers is also the result: awareness of the existing problem, generation and accumulation of knowledge about possible ways to solve it, and development and implementation of specific tools at each level of decision-making (within each system and structural component) (Fig. 1).

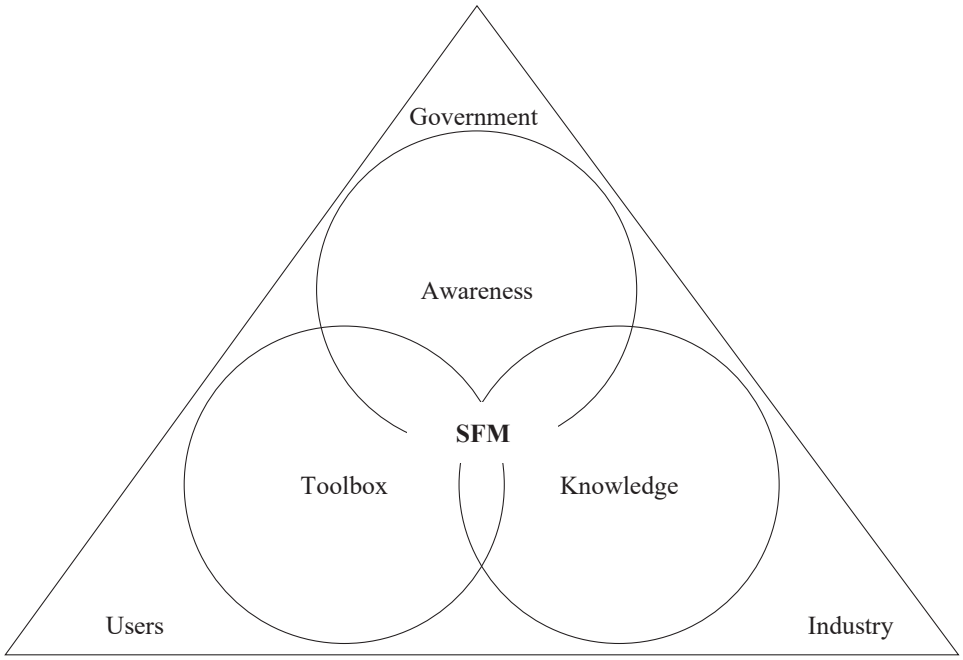

Figure 1. *National sustainable fertiliser management (SFM) system view: actors & component dimension*

Representatives of the industry, including individual economic agents — producers of agricultural products — act (make decisions) in accordance with their own economic interests, based on existing socio-economic and production conditions, resource opportunities and restrictions, and considering their own psychological attitudes. These are the main factors influencing decision-making (Pandey & Diwan, 2021), which are the embodiment of the components of the problem, respectively: knowledge, tools, and awareness. Consequently, the role of the government is crucial and consists in coordinating the economic interests of producers (the fertiliser industry and food producers) and society, forming a link between these interests and providing feedback (Helming *et al*., 2018). And the main component here should be ensuring awareness of the problem.

The problem that leads to the need to review fertiliser practices is that fertiliser application is perceived as a means of improving the productivity of agricultural enterprises in all conditions, and the negative consequences are largely overshadowed by fluctuating weather conditions and the associated risks to agricultural production (Pandey & Diwan, 2018).

Fertilisation, for the most part, appears as a means of obtaining short-term economic results against the background of limited resources, and the lack of direct manifestation of negative social and environmental consequences in the short term leads to neglect of them. An illustration of this, for example, is the results of study (Zand *et al*., 2020), which established that the impact of fertilisation on the sustainable development of rural areas is considered in the context of mainly economic and managerial components (protection of grain, income, reduction of production risk), and social criteria, such as protection and support of normal health of the population, were only on the 11th position out of 12 (Zand *et al*., 2020). Therefore, an urgent problem for the government is the transformation of long-term, socio-ecological and economic consequences of various practices of fertiliser use and management into understandable and acceptable categories for producers and industry, which are already important today — in the short term. Such a demonstration of backward impact, in addition to assessing the effects of anthropogenic activities on environmental components, may be more useful in terms of increasing public awareness of the problem of unsustainable fertiliser use. Actually, this approach is the basis of the concept of promoting the importance of Biodiversity Mainstreaming, where against the background of assessments of the impact of anthropogenic activities on the state of biodiversity and ecosystems, the consequences of the impact of disturbed ecosystems on the economic and social aspects of business development, industries, local population and society as a whole are also subject to study, control, and documentation (OECD, 2018).

Illustrating the dangers of irrational fertilisation through assessing the relationship between fertiliser application and cancer morbidity can best serve the purpose of raising awareness of the problem for other stakeholders, as shown by previous studies (Senesil *et al*., 1999).

Using statistical data in Ukraine for 2000-2019, a linear regression model of the relationship between the level of cancer incidence per 100 thousand population and the amount of mineral fertilisers in nutrients per 1 ha of sown area in Ukraine was constructed. Figure 2 shows a graphical representation of the results of correlation and regression analysis.

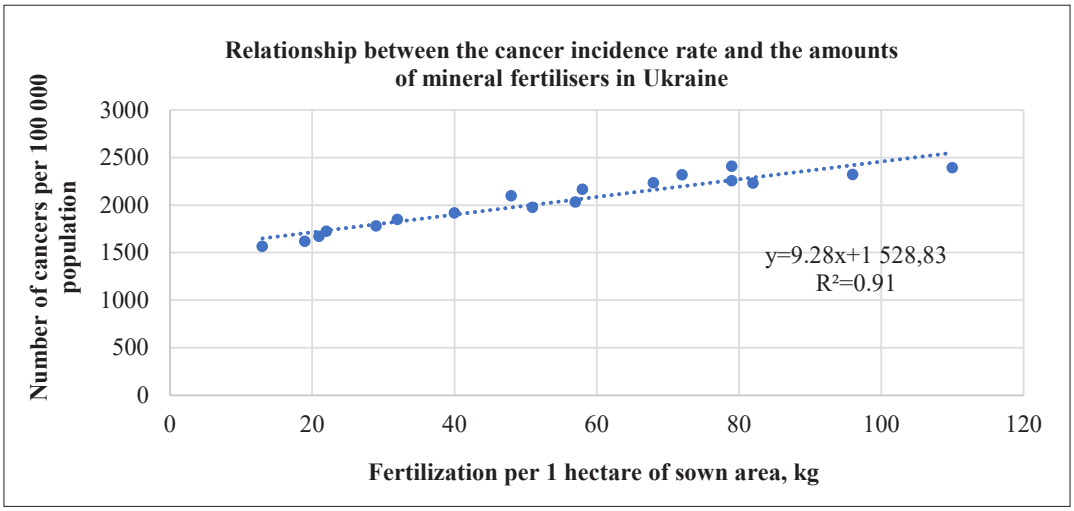

Figure 2. *Relationship between cancer incidence rate and the amount of mineral fertilisers in Ukraine*
Source: *compiled based on Ukrainian Statistics Service (n.d.)*

A linear regression model of the dependence of the analysed variables has the form (1):

$$y=9,2829x+1528,8 \quad (1)$$

The presented dependence indicates that with an increase in the volume of mineral fertiliser application by 1 kg, the number of cancer patients will increase by 9.29 people. Conversely, if the volume of mineral fertiliser application is reduced by 1 kg, the number of cancer patients will decrease by 9.28 people.

It is worth noting that the amount of mineral fertilisers depends on the type of soil, which determines fertility, humidity levels, humus and other nutrients, soil compaction levels, and many others. Different natural and geographical zones have their own soil types. Thus, the least fertile soils are located in the natural and geographical zones of Polissya. To assess environmental and economic losses from increased morbidity due to the chemicalisation of agriculture in the regional context, the relationship between the level of cancer incidence and the amount of mineral fertilisers by natural and climatic zones was analysed (Table 1).

Table 1. *Generalised results of the analysis for the natural and climatic zones of Ukraine for the period 2010-2019*

Indicators	Polissya	Forest-steppe	Steppe	Carpathian Mountain zone
Average volume of mineral fertiliser application, kg/ha	107.25	99.61	57.94	111.88
Average cancer incidence per 100 thousand people	2,084.21	2,496.26	2,567.17	1,913.53
Regression coefficient	6.0825	11.962	9.1718	11.047
Determination coefficient	0.8383	0.9079	0.7111	0.8689

Source: *compiled based on Ukrainian Statistics Service (n.d.)*

Such information, distributed among society, provides a broader understanding of the content and scale of the problem associated with irrational fertilisation practices. Analysis of the relationship between the amount of fertilisers applied and population health indicators, in addition to assessments of the state of soils, ecosystems, and biodiversity, forms not only a basis for informing society, but also a "knowledge" of the state of the problem, which can serve as a basis for developing regulatory tools.

The results of a quantitative assessment of the dependence of the level of cancer incidence on the amount of mineral fertilisers applied in the context of natural and climatic zones of Ukraine are of methodological and practical importance, since they form an information and analytical database for determining natural indicators of ecological and economic losses and/or the effects of increasing/decreasing population morbidity for further use in mechanisms to promote and support sustainable fertiliser management at the regional level.

Another aspect that requires more attention is the assessment of the specific economic consequences of irrational practices in the use and application of fertilisers within a particular territory (at the national, regional, and local levels). It is worth noting that now there are only approximate estimates of the economic damage to public health from the consumption of contaminated food, and there are few such studies. In studies of the late 20th – early 21st century (Shcherban, 2004; Tsarenko, 1998), economic losses from the consumption of contaminated food products in Ukraine were estimated in the range of USD 2,100-13,700 million. Considering the previous findings, based on the data of the average

annual comprehensive assessment of environmental damage caused by environmental pollution (air, water resources) in the context of regions for 2001-2009 (Sotnyk & Kerychok, 2012) and data on the typical structure of environmental losses (Karintseva, 2018; Starenko *et al.*, 2002), this study provides an approximate assessment of the harm to public health from the consumption of contaminated food in natural and geographical areas (Table 2), which is largely associated with the irrational use of fertilisers.

***Table 2**. Environmental and economic damage caused by environmental and food pollution, 2020**

Oblast/zone	Pollution damage	
	Environment	Food products
	Polissya	
Volynska	501.2	410.1
Zhytomyrska	918.9	751.8
Rivnenska	808.8	661.8
Chernihivska	829.2	678.5
	Forest-steppe	
Kyivska	1,250.2	1,023.0
Kyiv city	764.5	625.5
Vinnytska	673.2	550.8
Poltavska	649.0	531.0
Sumska	629.4	515.0
Kharkivska	901.3	737.4
Ternopilska	195.7	160.1
Khmelnytska	440.2	360.2
Cherkaska	475.0	388.6
	Steppe	
Dnipropetrovska	3,620.4	2,962.2
Donetska	4,936.5	4,039.0
Luhanska	1,700.7	1,391.5
Zaporizka	1,331.7	1,089.6
Kirovohradska	333.3	272.7
Mykolayivska	296.5	242.6
Odeska	808.7	661.7
Khersonska	414.8	339.4
	Carpathian Mountain zone	
Lvivska	1,004.9	822.2
Ivano-Frankivska	934.9	765.0
Chernivetska	376.7	308.2
Zakarpatska	514.7	421.1
Total	25,337.4	20,709.0

***Note**: * – in terms of the USD at the average annual exchange rate as of 2020*
***Source**: calculated by the author based on Karintseva (2018), Sotnuk & Kulyk (2014), Sotnyk & Kyrychok (2012), Tsarenko (1998)*

The methodology for assessing the total environmental and economic harm to public health (environmental and economic risk) has not yet been fully developed. Therefore, this determines a high level of approximation of such estimates. However, such assessments allow measuring the extent of environmental, economic, and social risks in a regional context and in accordance with natural and geographical zones, and thus make adequate and optimal management decisions for sustainable fertiliser management.

The results of the assessment of economic losses conditioned by irrational fertilisation are quite impressive. In fact, in the context of the country, they make up about 16.3% (if GDP is about USD 155.6 billion (for ecology) and 13.3% (for food) of Ukraine'S GDP) (Ministry of Finance of Ukraine, 2020). Thus, such data demonstrate the threat of irrational fertilisation at the national and regional levels. Therefore, one way to raise public awareness about poor fertilisation practice is to conduct regular studies on the impact of fertilisation and

management practices on public health; assess the economic damage caused by pollution of food consumption and disseminate the findings to the general public. As noted above, such data, on the other hand, form a "knowledge component" for the government, providing information about the state of development of the problem to choose tools for solving it.

The success of the national system for ensuring sustainable fertiliser management depends entirely on the relations and interaction between its subjects. Partnership, cooperation, and joint decision-making are the main components of effective and effective government-industry-user relations in this area (Colombo Declaration on Sustainable Nitrogen Management, 2019; FAO, 2019). The basic principles that should form the basis of the system of interaction of agents in ensuring sustainable fertiliser management can be formulated as follows:

– *professionalism* — decisions and tools used to ensure sustainable fertiliser management at the national level should be scientifically substantiated, based on the results of expert discussion, and reliable and relevant data. Notably, the efficiency of the agricultural sector of the economy is conditioned by investment in machinery and equipment only by third, and all the latter depends on the human factor, the intellectual potential used, the qualification level and abilities of managers and specialists;

– *transparency* — it is necessary to ensure a clear definition of the relationship "problem — solution — consequences" and equal conditions for all participants in the system. Transparency allows understanding where the most bottlenecks are in the system of sustainable use and management of fertilisers. In the future, this would allow saving resources, time, and obtaining socio-ecological and economic effects (income). Transparency provides greater "manageability" and not excessive controllability, as well as speed and optimality of decision-making (in particular, transparency helps to manage environmental and economic risks). At the same time, it is necessary to address the availability of information that comprehensively reflects the socio-ecological and economic aspects of fertiliser application practices;

– *scientific and innovative approach* — adequate support should be provided for research and development in the field aimed at both technological solutions and research of the socio-cultural and institutional environment. Innovation in the development of sustainable use and management of fertilisers should see not only an economic orientation, but also a special type of attitudes (in particular, ecological-economic, socio-ecological), value attitudes (public health and food and environmental safety), and motivations (for example, the use of the institute of socio-environmental responsibility). Innovation should determine the trajectory of convergence of economic, environmental and social parameters (guidelines) of fertiliser application practices, which will also be reflected in the socio-cultural and institutional environment;

– *knowledge* — it is necessary to ensure constant monitoring of the state of development of the problem (assessment of the diverse socio-ecological and economic impact of fertiliser use practices), monitoring and tracking, accumulation of innovative technological solutions to solve existing problems. It should be about knowledge management as a component of sustainable fertiliser management. Knowledge management covers the processes of identification, accumulation, use, and transfer of information and knowledge, which are used in determining and evaluating the "problem — solution — effect" relationship at all stages of fertiliser production and use. It is necessary to constantly deepen awareness (knowledge) about the socio-ecological and economic aspects of fertiliser use. Therefore, it is important to develop and accumulate knowledge about the relationship between health care and human capital (in particular, which is considered as a factor of economic growth and can be the subject of a separate study);

– *information support and solution support at all levels* — it becomes possible today due to the increasing spread of information technologies and consists in creating a single information system that would combine data on the volume of production, use, utilisation of fertilisers, data on the characteristics of fertilisers, the results of assessments and tests of soil condition and nutrient needs, data on volumes and beneficiaries of state support in the industry. Information support should cover regulatory reference, accounting and analytical, operational and technical, and forecast information. At the same time, it is important that the processes of formation and development of a sustainable fertiliser management system do not lag behind Information and analytical support and vice versa. It is important that there is no asymmetry in the information support of management processes. Thus, information support should ensure timely implementation of direct and reverse links in the management decision-making system regarding the use of mineral fertilisers;

– *trust* — it is necessary to ensure an appropriate level of trust between all agents of the system, which is the result of professionalism, transparency, and proper information support. A high level of trust is a necessary condition for the sustainable development of the fertiliser use and management system, since distrust indicates certain conflicts, conflict situations, and crisis phenomena. Trust is also a specific mechanism for making managerial decisions in conditions of time constraints, incompleteness or asymmetry of information. It helps to reduce transaction costs, increase balanced productivity, and efficiency of agricultural management, and reduce eco-destructiveness in the practice of applying fertilisers. In a crisis economy it is also important to build ecologically-oriented institutional trust;

– *system constancy* — provision of conditions for the further automatic operation of the system, which can be achieved through proper information support, the development of an appropriate level of trust between participants. This principle also determines the need to assess the effectiveness of the application of information support, quantitative measurement of trust, and the effectiveness of the functioning of the whole system.

The development of a national system of sustainable fertiliser management also requires defining the main strategic performance and targets of production,

economic, environmental, and social orientation for the agents of this system. Such main performance targets can be presented as follows:

1. Production and economic:

1.1. Activation of innovation and investment activities for greening reproductive processes in the system of sustainable fertiliser use;

1.2. Growth in the production of environmentally friendly agricultural and food products;

1.3. Activation of marketing activities for the production of environmentally friendly agricultural products;

1.4. Development of "green" logistics;

1.5. Prevention of economic damage caused by the eco-destructive state of agricultural land and water objects due to irrational use of fertilisers;

1.6. Reduction of the cost of environmental protection measures;

1.7. Obtaining a rental effect due to an increase in the monetary valuation of eco-balanced, eco-safe agricultural land and water objects;

1.8. Increase in tax revenues from business entities through the system of environmental taxes and payments;

1.9. Improvement of the level of eco-oriented integration of agriculture, water, fish, and forestry in the organisation of sustainable land use (in particular, based on agroforestry management of agricultural landscapes);

1.10. Gradual introduction of environmental management elements;

1.11. Development of geoinformation systems and IT technologies, monitoring systems of socio-ecological and economic areas for information support;

1.12. Improvement of the "green" image and corporate environmental culture in agent relations;

1.13. Increase in the cost of human capital.

2. Environmental:

2.1. Reduction of environmentally related morbidity in the population;

2.2. Preservation and improvement of physical, chemical, and reproductive properties of soils, and fertility of agricultural lands;

2.3. Reduction of the level of anthropogenic load on land and aquatic ecosystems;

2.4. Reduction of the environmental risk of reducing the productivity of agriculture, water, and forestry management;

2.5. Improvement of the overall and field-protective forest cover at various hierarchical levels of simple development, and, as a result, improving the ecological quality of the agro-natural environment;

2.6. Conservation and improvement of biodiversity and genetic potential in agroforestry landscapes.

3. Social:

3.1. Improvement of the quality of life, improving the level of social and environmental safety, and comfort of life;

3.2. Creation of "green" jobs (for example, for the implementation of agroforestry measures);

3.3. Development of social and environmental responsibility mechanisms;

3.4. Development of social entrepreneurship;

3.5. Development of social infrastructure;

3.6. Improvement of the public consciousness, culture, and spirituality of territorial communities.

Embodying the content of global initiatives for sustainable fertiliser management and the expected results of their implementation, outlined in this way and reflected in the action plans at the national, regional, and local levels, these guidelines can lay the foundation for the development of economic mechanisms to encourage the implementation of best practices, the development of a monitoring and control system for fertiliser management.

The national system for ensuring sustainable fertiliser management can be represented as a complex of interactions between the government, the industry for developing, producing, and transferring fertilisers to users, including agricultural producers – fertiliser users, whose functioning is a continuous process of raising awareness of problems caused by irrational practices of fertilisation, generating, accumulating, and spreading knowledge about the possibilities of solving them and developing and applying appropriate tools.

Sharing an opinion of Helming *et al.* (2018) regarding the role of government as a link between the goals of society and the individual goals of fertiliser users, it is necessary to point out its leading role in raising awareness among all agents of the system about the problems caused by irrational fertiliser use. Notably, the low level of awareness of the society in this area is one of the main obstacles to the successful implementation of global initiatives in this area (Sutton *et al.*, 2019). On the other hand, the role of government should also be reviewed due to the inefficiency of command and control mechanisms in the field of regulating the use and management of fertilisers: it is almost impossible to control all operations with fertilisers; through regulation in one area, there may be effects of shifting externalities to other industries and spheres, countries; the benefits obtained may be accompanied by side effects; it is impossible to reflect the complexity of individual phenomena (for example, biodiversity) through a command and control approach (Garske *et al.*, 2020).

The leading role of the government in the national system of ensuring sustainable fertiliser management should be to transform the existing institutional environment to be filled with more information and knowledge (Golicz *et al.*, 2021). Raising public awareness of the problem is a trigger for generating knowledge for all participants in the system (Adnan, 2018). The basis for attracting public attention to the problem and forming public awareness is considered the impact assessment, which should serve as the basis for developing/transforming policies in accordance with the goals set by society, overcoming suboptimality and ensuring the consistency of policies (Helming *et al.*, 2018). Such estimates are usually based on negative impact on environmental components and soil health (Hou *et al.*, 2020), ecosystems, and resource efficiency (Helming *et al.*, 2018). Expanding the range of aspects studied, considering the

impact of fertilisation on public health and the reverse impact of contaminated components on the economic performance of industries, regions, countries, is appropriate and especially significant for developing countries, illustrating the socio-economic side of the problem of fertilisation and the corresponding social costs (Mishenin *et al*., 2015; Mishenin *et al*., 2021).

Methodological and practical tools for assessing environmental and economic damage caused by the consumption of contaminated food products have not yet been developed (Karintseva, 2018; Kubatko, 2017; Yang *et al*., 2017). Thus, the expansion of the information and analytical base of such consolidated damage estimates, in particular, by natural and geographical zones, opens up opportunities for informing and regulating sustainable fertiliser management at the national and regional levels.

Considering the issues of generating and transferring knowledge on sustainable fertiliser management (Adnan *et al*., 2018) researchers note the prospects of cooperation between different agents to achieve better results. For example, joint research with farmers is seen as a source of innovation and successful solutions (Kröbel, *et al*., 2021), and field support of farmers ensures that they acquire the best knowledge on the use of fertilisers (Yu *et al*., 2020). Therefore, the interaction of agents of the national system for ensuring sustainable fertiliser management should be at the centre of attention.

CONCLUSIONS

The findings show that the national system for ensuring sustainable fertiliser management should be considered as a set of interacting entities (government, industry representatives, and fertiliser users) involved in the process of continuous improvement of fertilisation practices through raising awareness of the problem — generation and transfer of knowledge to solve it — selection and implementation of appropriate tools. Such a system should be based on the principles of professionalism, transparency, scientific and innovative nature, knowledge, information support, trust, and constant functioning of the system in the long term. In the context of improving fertiliser management practices, it is necessary to point out the need to formulate strategic performance targets for all parties involved (developers, producers, users of fertilisers), which should prioritise not only production and economic targets, but also environmental and social ones. Such guidelines can be further used as the basis for monitoring and evaluation mechanisms, and economic incentives for sustainable fertiliser management practices. The results obtained can serve as a basis for further shaping policies and strategies for sustainable fertiliser management and use at national and lower hierarchical levels.

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Реалізація глобальної ініціативи з управління добривами на національному рівні: концептуальні засади

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Анотація. Нині перед людством стоїть завдання пошуку балансу між необхідністю збільшення кількості продовольства та негативними соціально-екологічними та економічними наслідками нераціонального використання добрив. На глобальному рівні було започатковано ряд ініціатив для консолідації зусиль країн у вирішенні цієї проблеми. Втім, існуючі національні системи та політики з управління добривами характеризуються недостатньою системністю та низькою ефективністю. Дане дослідження націлене на формулювання концептуальних засад для розбудови національної системи сталого управління добривами, що відповідала би принципам, викладеним в існуючих глобальних ініціативах. Через узагальнення змісту існуючих міжурядових ініціатив щодо сталого управління добривами було сформульовано суб'єктний склад, а оцінки взаємозв'язку між внесенням добрив та здоров'ям населення (через кількість онкозахворювань) за допомогою використання методів регресійного аналізу, оцінки економічного збитку від нераціонального добрення слугували обгрунтуванням (ілюстрацією важливості виділення) компонентних складових, що охоплюють: обізнаність, знання, інструменти. Національна система сталого управління добривами розглядається як тривимірна цілісність, що містить такі взаємопов'язані складові: уряд, галузі з виробництва та постачання добрив та користувачі. Функціонування цієї системи розглядається як безперервний процес підвищення обізнаності, генерування та передачі знань, вибору та застосування відповідного інструментарію та вдосконалення практик застосування добрив відповідно до принципів сталого розвитку за провідної ролі уряду. Процес підвищення обізнаності всіх суб'єктів системи щодо проблеми нераціонального внесення добрив пропонується розглядати в ширшому контексті — через демонстрацію негативних наслідків не лише для навколишнього середовища (стану ґрунтів), а й з точки зору впливу на здоров'я населення та відповідних наслідків — через оцінку економічних збитків, спричинених забрудненням та споживанням продовольства з вмістом шкідливих речовин. Головними принципами взаємодії суб'єктів у цій системі мають стати такі: професіоналізму, прозорості, інформаційної підтримки та ін. Особлива увага має бути приділена формулюванню комплексу стратегічних цілей, що мають закласти основу для розробки процедур контролю та оцінки, системи моніторингу та перегляду механізмів економічного стимулювання використання добрив з урахуванням соціальних та екологічних аспектів застосування добрив

Ключові слова: стале управління добривами, національна політика щодо добрив, обізнаність, трансфер знань, безпечне добрення, продовольча безпека