JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(2), 274–289
https://doi.org/10.12911/22998993/177275
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.12.08
Accepted: 2023.12.23
Published: 2024.01.01

Ecotoxicological Hazard of Pesticide Use in Traditional Agricultural Technologies

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ABSTRACT

The ecotoxicological hazard assessment of pesticide use on crops was performed. The study was conducted in 2021-2023 at the experimental field of the Skvyra Research Farm of the Institute of Agroecology and Environmental Management of National Academy of Agrarian Sciences of Ukraine, located in the Forest-Steppe zone of Ukraine. The influence of herbicides, insecticides, and fungicides on the formation of environmental hazards in crop agrocenoses was studied: experiment (1) – peas, winter wheat, buckwheat; experiment (2) – winter wheat, buckwheat, oats. The ecological risk was assessed taking into account the ecotoxic properties of the chemical active ingredients of pesticides. It was found that the main parameters characterizing the occurrence of environmental risks are: (i) the pesticide load, i.e. the amount of toxicant applied per unit of sown area; (ii) the ecotoxicity of the pesticide (LD_{50}), which is established by hygienic standards; (iii) the persistence of the pesticide in the soil, namely, its half-life (DT_{50}), etc. The calculations proved that the pesticides used had a low environmental risk of impact on agrocenoses. This is evidenced by the ecotoxicity index (E). The total pesticide load (Σ_E) on the agrocenosis of each crop during the three years of the study (2021–2023) was calculated. It was found that in experiment (1) – $\Sigma_{\text{Experiment 1}}$ = 0.23 conventional units (c.u.); in experiment (2) – $\Sigma_{Eexperiment\ 2}$ = 0.04 c.u. The results obtained indicate an insignificant environmental risk of pesticide use for experimental plots of crops of the studied farm. However, prolonged use of pesticides certainly leads to the concentration of their persistent residues in the soil. This can lead to contamination of crop products and environmental. The cereals (buckwheat and oats) grown on the farm are intended for dietary consumption. To confirm the reliability of the hypothesis of the safety of the obtained grain and cereal products, it is advisable to further study their quality in terms of pesticide residues. It is shown that this methodology can be used to assess the risk of pesticide contamination of an agroecosystem. The ecotoxicity criterion (E) can be considered as a management tool for reducing environmental risks in agroecosystems.

Keywords: agrocenoses, pesticide pressure, pesticide contamination, ecotoxicity, ecological risk, agricultural crops, environmental risk management, ecological safety.

INTRODUCTION

Environmental risk is important indicators of environmental safety. This indicates the possibility of negative changes in the environment caused by natural or anthropogenic factors. In turn, environmental safety is related to the use of agricultural technologies, which can lead to occurrence of the environmental risks in agricultural sector. The result of environmental risks in agriculture, as one of the most vulnerable sectors of agricultural production, is an imbalance in the ecological state of agroecosystems. Among the most important anthropogenic factors that play a decisive role in the occurrence of environmental risks in crop agrocenoses are: pesticide pollution, which affects the physiological characteristics of the development of plants; the formation of the phytosanitary state of agrophytocenosis during the development and emergence of various types harmful and phytopathogenic organisms that affect crop yields (Lishchuk et al. 2022, 2023; Moklyachuk et al. 2012).

The widespread use of pesticides has become an extremely important ecological issue worldwide. Xenobiotic cause toxic contamination of soils, water objects, and agricultural products, and pose a serious threat to agricultural production and human health (Wee et al. 2017). They are at the top of the list of ecotoxicants that pose significant ecotoxicological hazard in the environment (Alengebawy et al. 2021; Tongtong et al. 2022). The deterioration of the phytosanitary condition of agrophytocenoses encourages agricultural producers to use artificial pesticides, increase their doses and spectrum. This causes severe chemical pressure on pathogenic and beneficial biota and significantly affects biotic diversity, unbalancing the set of plant and microbial species and their communities in agrophytocenoses (Drebot 2022).Conventional agricultural practices pose a high risk to soil biological activity and can disrupt the functional activity of soil biota (Panico et al. 2022).

The main problem of soil contamination with pesticide residues is related to their high persistence in the soil and their toxicity to humans. The study by Bhandari et al. (2020) confirmed the potential risks of pesticide residues to public health in Nepal. Scientists have found that about 60% of the 147 soil samples studied contained pesticides, with the vast majority of their residues found in the upper (0-5 cm) soil layer at concentrations ranging from 1.0 μg/kg to 251 μg/kg of pesticides. Among them, the predominant soil contaminants were organophosphorus and organochlorine pesticides, in particular, chlorpyrifos, and trichloropyridinol. The determined concentrations of pesticides in the soil were higher than the values specified in the guidelines used internationally. According to the Chinese standard (GB 15618-2018), the permissible level of dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCCH) is 100 μg/kg (GB 15618-2018). Meanwhile, the ratio of DDT and its metabolites showed the continued use of this organochlorine pesticide in the study area of Nepal. First of all, among DDT breakdown products, the predominant compound is its metabolite DDE (Bhandari 2020). Even trace amounts of organochlorine pesticides such as HCCH and DDT, which were historically used for decades in agricultural activities during the Soviet era, can easily accumulate to levels of potential environmental concern through biological amplification in the food chain (Li et al. 2020).

According to many scientists around the world, pesticide risk assessments for environment are based on indicators – quotient (HQ) and index (HI) hazard (Hu et al. 2014; Pan et al. 2018; Sun et al. 2016), and on predicted indicators of pesticide content in environmental objects (*PEC*) (Vasickova et al. 2019; Silva et al. 2019). There is limited information in the international literature on the methodology for assessing the ecological risk of pesticide use.

Irrational use of pesticides can cause a number of environmental risks, such as the destruction of non-target organisms, poisoning of farmers, and dispersion in the environment. This causes not only localized pollution, but also leads to global environmental contamination (Carvalho 2017). The intensive use of a range of chemical pesticides leads to pesticide persistence in the soil, which is caused by the lack destruction of highly toxic chemical compounds. Their degradation in the soil is to some extent limited due to high structural stability and low solubility of pesticides, slowed down physicochemical and biochemical processes, which limits the availability for degradation by plants and soil microbes (Umadevi et al. 2017; Prabha et al. 2017).

Yang et al. (2022) argue that predicting the pesticide load on agrocenosis involves studying the ecotoxic properties of xenobiotics, their persistence, ability to accumulate and degrade by soil biota, etc. The results of the forecasting can be used to formulate a model for the management and regulation of environmental risks to prevent environmental degradation of soil and to achieve the goal of soil health and green agricultural development (Yang et al. 2022).

In the study of pesticide residues in agricultural soils accumulated during previous growing seasons in the Czech Republic, the ecological risk for agroecosystems was determined by the content of potentially hazardous compounds of organochlorine pesticides, mainly for triazine and chloroacetanilide (amides, chloroacetamides) chemical classes. Persistent pesticides have been shown to persist in the soil for many growing seasons. The risk assessment showed that pesticide residues in the soil posed a danger to 35% of the studied sites ($R \geq 1$). Among the hazardous pesticides, epoxiconazole, dimoxystrobin, carbendazim, atrazine-2-hydroxy, and others were found in concentrations that far exceeded the limit values (Vasickova et al. 2019).

Neuwirthová et al. (2019) proved that pesticide residues remaining in the soil of Czech arable land from previous growing seasons accumulate in non-target organisms (the study was conducted on earthworms and lettuce plants). However, the potential for toxic residues to bioaccumulate in earthworms and lettuce was negligible. In soil, residues of tebuconazole, epoxiconazole, pendimethalin, flusilazole, prochloraz and atrazine conversion products (atrazine-2-hydroxy) at levels ≤0.1 mg/kg did not pose an environmental threat to the soil environment, food web and human health (Neuwirthova et al. 2019).

At the same time, Yang et al. (2022) found multicomponent contamination of soils in the ecosystem near the Three Gorges Reservoir (TSR) by pesticide residues. Among them, the herbicide glyphosate and pyrethroid insecticides accounted for the largest share in concentrations exceeding the maximum permissible levels. It has been noted that residues of the pesticides fenpropathrin, chlorphenapyr, β-cyfluthrin, and glufosinate pose a significant threat to agroecosystems in the next 50 years (Yang et al. 2022). Residual amounts of herbicides belonging to the sulfonylurea group can affect a heterogeneous group of nitrogen-fixing bacteria (Rhizobium) and lead to a decrease in the nitrogen-fixing capacity of legumes in the following years (Rose et al. 2022).

Danish scientists use a pesticide load (PL) assessment based on three indicators that are key to assessing the relative potential environmental risk. The pesticide load (PL) is determined by the following indicators: 1) the human health impact indicator (HI), which is based on the risk phrases on the pesticide label; 2) the ecotoxicological impact indicator (PL_{ECO}), which is calculated on the basis of acute toxicity values ($LC/LD/EC_{50}$) for mammals, birds, fish, earthworms, algae and bees and chronic toxicity values (NOEC) for fish, earthworms, etc. 3) by the environmental health index (PL_{FATE}), he takes into account the persistence of the toxicant in terms of its half-life in soil (DT_{50}), bioaccumulation factor (BCF) and potential leaching into groundwater (SCI-GROW) (Kudsk et al. 2018). Instead, Kookana and Oliver (2018) believe that to assess the risk of pesticide burden on the agroecosystem, you need to take into account the complex range of chemical properties of xenobiotics and environmental properties. The indicators used should primarily define a comprehensive approach to assessing the ecological risk of pesticide hazards to soil health and ecosystems (Kookana and Oliver 2018). Another group of scientists considers another approach to assessing the relative ecological risk of pesticides in agriculture (Sanchez-Bayo et al. 2002). The authors propose to calculate the relative environmental risk for each individual site. Therefore, necessary to pay attention the dose of the pesticide used, its ability to migrate and translocate, and its accumulation in the soil profile, vegetation, surface and groundwater. An important component in the calculations is the pesticide degradation rate, its persistence in soil and other components of the agrosphere, its bioaccumulation in animal tissues, and its toxicity to living organisms and humans. Instead, Tian et al. (2018) propose to assess the environmental risk for a mixture of pesticides based on the combined toxicological effects of the active ingredients.

The methodology for calculating the ecotoxic effect of pesticides (*ecotox E*) was proposed in the soil for the assessment of ecological risk in Ukraine (Melnikov 1987). This methodology was modified by Petruk et al. (2019, 2020, 2021) and improved by scientists for an integrated assessment of the potential environmental hazards of modern pesticide products. The essence of the modified method is the ability to predict the toxic impact of xenobiotics on various environmental objects and model the optimal mechanism for minimizing the harmful effects of the toxicant.

The migration of pesticides in the ecosystem is very important for assessing the risks of their hazardous effects. This applies especially to residues of highly persistent substances that can be deposited, i.e. accumulate and remain in the soil for a long time. During the next growing season, under favorable conditions, persistent toxicants accumulated in the soil are translocated from the soil to crops in rotation and accumulate in agricultural products, are involved in the "food chain" and pose significant environmental risks (Monaci et al. 2017). Such hypotheses are confirmed by the research of Martiyanova, Korshun et al. (2021, 2022, 2023), who established a limiting indicator of pesticide harmfulness, which actually identifies the leading link in the migration of toxicants. It was found that in 60% of cases, toxicant migration occurs in the soil-plant system. Meanwhile, 23% of the 93 xenobiotics they studied migrated in the soil-water system (Martiyanova and Korshun 2021; Korshun et al. 2022, 2023). This is especially true for plants that are hyperaccumulators of toxic substances.

Indeed, according to Tsytsyura et al. (2022), who studied the phytoremediation properties of more than 450 species of hyperaccumulator plants, it was found that many crops are among them. Among them, it is especially important to identify highly productive plants with a high rate of removal of pollutants from the soil. Among such crops, plants of the cruciferous family, Sarepta mustard (*Brassica juncea*), spring rape (*Brassica napus*), sorghum (*Sorghum bicolor* L.), buckwheat (*Polygonum* L.), safflower (*Carthamus* L.), white mustard (*Sinapis alba* L.), oats (*Avena sativa* L.), and many others occupy a significant place (Tsytsyura et al. 2022). Their cultivation characteristics are typical for the Forest-Steppe zone of Ukraine.

It has been proven that rational agronomic practices can have a positive impact on reducing environmental hazard from the use of pesticides to achieve green agricultural development in TGRA (Zhou et al. 2023, Li et al. 2023). Along with the danger, we cannot ignore the effectiveness of the use of chemical plant protection agents (CPPAs), which is a high economic return. This is reflected in high yields and environmental safety in the case of a coordinated and integrated approach to agriculture and the rational use of CPPAs. Pesticides used to control plant pests and diseases help regulate the phytosanitary condition of crops, which can improve yields and product quality. For example, Vasylenko (2018) confirmed in his research that the effectiveness of pesticide use is manifested in a positive impact on agriculture and provides the following important benefits

- regulation of the number of pests and diseases contributes to an increase in crop yields;
- reducing the impact of pests and diseases on agrocenosis reduces plant stress and increases the productivity of agricultural land;
- chemical protection of plants from pests and diseases helps to preserve plant residues, which are important for restoring soil structure and nutrients;
- the use of pesticides that have minimal impact on beneficial soil microorganisms helps maintain soil health and biological activity, which, in turn, ensure soil suppression;
- reducing the need for manual labour to control weeds and other pests can be particularly effective on large agricultural lands.

However, it is important to note that the effective use of pesticides must be accompanied by consideration of environmental safety and the rational use of crop protection chemicals (CPC_S) to preserve ecosystems and human health. Modern agronomic practices, such as integrated crop protection systems and environmentally friendly methods using biological products, can strike a balance between high crop yields and the ecological sustainability of the agroecosystem. This opinion is supported by other scientists around the world (Kumar et al., 2021; Ruiu 2018), who think that the use of biopesticides can be more effective than traditional chemical pesticides. The advantages of their use are: environmental friendliness, precise and targeted control of specific pests, lack of resistance to the target pest, promotion of beneficial microorganisms in the soil; combination with other methods of integrated plant protection; reduction of environmental risk to the ecosystem and humans.

In general, the effectiveness of any pesticide depends on its quality, proper application and correct timing. This is because each pesticide with a specific mechanism of action must match the biological characteristics of pests, diseases and weeds, as well as the relevant phases of crop growth and development, when pests are most vulnerable. Understanding the development cycles of pests and plants helps to determine the optimal timing of pesticide applications and to take into account the possibility of resistance development. Integrated plant protection, which combines various methods of pesticide control, biological control and environmentally friendly methods, can be more effective in regulating the phytosanitary condition of crops and minimizing hazardous ecotoxicological impact on the environment. Thus, the issues under consideration are becoming relevant, as it is now important to find ways to reduce the environmental risks arising from the use of pesticides

In our opinion, it is especially important to study the ecotoxicological hazard to the agroecosystem due to long-term pesticide exposure. The interest of such research is currently focused on the study of the ecological state of soils due to the pesticide load on in previous growing seasons. Therefore, the purpose of the research was to study environmental risks in crop agrocenoses during (or as a result of) a three-year pesticide load; to determine the possibility of reducing the potential danger of environmental risks in land use in Ukraine.

MATERIALS AND METHODS

The research work was carried out in the Department of Agrobiological Resources and Environmentally Friendly Technologies of the Institute of Agroecology and Environmental Management of National Academy of Agrarian Sciences of Ukraine (IAEM NAAS). The work was carried out in the period of 2021–2023 on the production field of the State Enterprise "Experimental Farm "Skvyra" of the IAEM NAAS" (hereinafter referred to as "Skvyra"). Field experiments were conducted on land plots with a total area of 77 hectares (arable land), of which: experiment No. 1 was located on fields No. 8, 11/4 and 12 with a total area of 37 hectares; experiment No. 2 – on fields No. 3, 11, 15 with a total area of 40 hectares. The experimental scheme included the cultivation of crops in crop rotation: peas – winter wheat – buckwheat – oats. The experiment was repeated three times at each site (Table 1). The system of chemical protection of crops from pests involved the use of the following pesticide preparations at the rate of consumption:

- experiment 1: on peas – herbicide Agritox (a.i. 2-methyl-4-chlorophenoxyacetic acid in the form of dimethylamine salt (MCPA DMA Salt)), 500 g/l), 0,5 l/ha; insecticides Fosorgan Duo (a.i. cypermethrin, 500 g/l + chlorpyrifos, 50 g/l), 1,0 l/ha and Dimefos (a.i. dimethoate, 400 g/l), 1,0 l/ha; for winter wheat – herbicide Granstar Gold 75 (a.i. tribenuron-methyl, 562,5 g/kg + tifensulfuron-methyl, 187,5 g/kg), 0,025 kg/ha; fungicide for seed treatment Vitavax 200 (a.i. carboxylic acid, 200 g/l + tiram, 200 g/l), 3,0 l/t; fungicides Rex Duo (a.i. epoxiconazole, 187 g/l + thiophanate-methyl, 310 g/l), 0,6 l/ha and Tilt 250 (a.i. propiconazole, 250 g/l), 0,5 l/ha; no pesticides were used on buckwheat;
- experiment 2: on winter wheat – herbicide Granstar Gold (a.i. tribenuron-methyl, 562,5 g/kg + tifensulfuron-methyl, 187,5 g/kg), 0,025 kg/ha; fungicide for seed treatment Vitavax 200 (a.i. carboxylic acid, 200 g/l + tiram, 200 g/l), 3,0 l/t; fungicides Rex Duo (a.i. epoxiconazole, 187 g/l + thiophanate-methyl, 310 g/l), 0,6 l/ha and Tilt 250 (a.i. propiconazole, 250 g/l), 0,5 l/ha; no pesticides were used on buckwheat; on oats – herbicide Grenadier Maxi (a.i. tribenuron-methyl, 562,5 g/kg + tifensulfuron-methyl, 187,5 g/kg), 0,025 kg/ha; fungicide Tinazol (a.i. propiconazole, 250 g/l), 0,5 l/ha.

The territory of the research plots is located in the forest-steppe of Ukraine. Experiments were conducted on low-humus chernozem, which is typical for this region. The ecological hazard of the use of pesticides in experimental areas during 2021-2023 was assessed according to the method of determining their ecotoxicity (*E*) according to Melnikov (1987). The method includes the calculation of the ecotoxic effect of pesticides on environmental objects according to formula 1:

$$E = \frac{P \cdot N}{LD_{50}} \quad (1)$$

where: *E* – ecotox, or ecotoxicological hazard, conventional units (c.u.); *P* – the half-life of the pesticide in the soil (DT_{50}), weeks; *N* – the rate of consumption of pesticide, kg, l/ha; LD_{50} – the average lethal dose for rats, mg/kg.

Ecotox standard (*E*=1) is accepted ecotoxicity of dichlorodiphenyl-trichloromethyl-methane (DDT), which is the most toxic and persistent organochlorine pesticide. DDT has been banned since 1972 in Ukraine and many countries of the world. However, the widespread use of this dangerous persistent pesticide in agricultural production in the past, and to this day, has had negative consequences. Current research shows that its residual concentrations still cause contamination

Table 1. Predecessors in crop rotation for growing buckwheat and oats in Skvyryska State Farm, 2021-2023

Experiment, No.	The experimental field, No.	2021	2022	2023
1	No.: 8, 11/4, 12	Peas	Wheat winter	Buckwheat
2	No.: 3, 11, 15	Wheat winter	Buckwheat	Oats

of the environment – soil, water, and food – and remain an urgent and priority problem in Ukraine (Moklyachuk et al. 2015, 2017; Srivastav 2020).

In general, the ecotoxic effect of pesticides (Σ_E) on the experimental sites consists of the sum of the ecotoxic effects (E) of the chemical active substances of pesticides according to formula 2:

$$\Sigma_E = E_1 + E_2 + \ldots + E_n \quad (2)$$

and assessed the average hazard level of all applied pesticides in the study area. Field, methods of systematization, analysis and generalization of information, and calculation and statistical methods as the research methods were used in the work.

RESULTS AND DISCUSSION

Evaluation of the chemical crop protection system on the experimental plots of Skvyryske State Farm in 2021–2023. Under traditional crop cultivation technologies, the chemical plant protection agents ($CPPA_S$) involves the use of pesticides. Their assortment depends on the phytosanitary condition of the agrocenosis. In order to prevent in agrocenoses the increase of ecological risks, it is extremely important to adhere to the timely regulation of phytopathological control of agrocenoses. Therefore, a set of pesticides used of the Skvyryska State Farm for $CPPA_S$ of pea, wheat winter, buckwheat and oat agrocenoses in 2021–2023 was analysed. It has been established that the plant protection pesticide system was developed taking into account the varietal characteristics of the crops grown and the phytosanitary state of agrocenoses.

According to Pysarenko et al. (2019) and Stepanenko and Polyovyi (2018), climate change has led to a trend of changes in crop acreage associated with the shift of climatic zones to the north and west of Ukraine. The consequence of this trend is the expansion of the distribution areas and changes in the species number of weeds, pests, pathogens and other harmful organisms that were not previously characteristic of these areas. Due to the expansion of grain crops, weeds such as common wheatgrass, creeping wheatgrass, pink thistle, field thistle, etc. are weeding winter wheat crops. The most widespread pests of wheat winter are bread borer (*Zabrus tenebrioides* G.), cereal fly (*Phorbia secures* Tien), winter moth (*Agrotis segetum* Schiff), cereal aphid (*Schizaphis graminum* Rond), striped aphid (*Psammotettis striatus* L.) and bread flea (*Siphonaptera padi* L. (Aphis)), wheat thrips (*Haplothrips tritici* Kurd), bread sawfly (*Cephus pygmeus* L.), (*Oulema lichenis* Voet.), harmful shell bug (*Eurygaster integriceps* Put.), bread beetle (*Anisoplia austriaca* Hrbst.). The most common pathogens are various types of smut (Tilletia spp.) and rust (*Puccinia* spp.), septoria (*Mycosphaerella graminicola* J.), spot (*Bipolaris sorokiniana* Shoem.) and root rot (*Fusarium* spp.).

Pea is a sensitive crop to excessive weed infestation, which can reduce the yield by 50% or more. The most common annual weeds in pea crops in the forest-steppe of Ukraine are: white quinoa (*Chenopodium album* L.), radish wild (*Raphanus raphanistrum* L.), common bindweed (*Amaranthus retroflexus* L.), common fescue (*Elytrigia repens* L.), blue mousegrass (*Setaria pumila* L.), and chicken millet (*Echinochloa crus-galli* L.). Among perennial root and sprouting plants, pea (Pisum sativum L.) crops are most often infested by such species as thistle pink (*Cirsium arvense* L.), yellow field thistle (*Sonchus arvensis* L.), yellow (rough) thistle (*Sonchus asper* (L.) Hill), creeping wheatgrass (*Elytrigia repens* L.), bindweed field (*Convolvulus arvensis* L.), etc. Tangible damage to pea (*Pisum sativum* L.) crops is caused by striped weevils (*Sitona lineatus* L.) and weevil bristle (Sitona crinitus L.), weevil pea (*Bruchus pisorum* L.), aphid pea (*Acyrthosiphon pisum* Harr.), pea moth (*Cydia nigricana* F.), cabbage moth (*Mamestra brassicae* L.) and pea moth (*Ceramica pisi* L.), bean moth (*Etiella zinckenella* Tr.), thrips (*Thysanoptera* spp.) and others. Significant damage to the pea crop can be caused by pathogens such as Fusarium spp., Ascochyta pisi, powdery mildew (*Erysiphe communis* Fr. f. pisi Dietrich), rust (*Uromyces pisi* Schroet), etc. Ascochyta pisi L. infection of pea seeds cause loss of germination, which can lead to significant thinning of crops.

Varietal characteristics of modern buckwheat (*Fagopyrum esculentum* L.) varieties intended for cultivation in arid conditions are characterized by high resistance to unfavorable, rainless, hot periods. They tolerate windy weather and are resistant to lodging. The zoned buckwheat varieties are mostly resistant to the most dangerous and widespread diseases (powdery mildew (*Erysiphales* spp.), mildew downy (*Peronospora fagopyri* Elenev) and Didymella pinodes (Berk. & A. Bloxam Petr.) and the spread of insect pests, which are usually inherent in this crop. To prevent weed infestation of agrocenoses in the areas of the forest-steppe zone, buckwheat (*Fagopyrum esculentum* L.) is best grown on weed-free fields after beet sugar (*Beta vulgaris saccharifera* L.), potato (*Solanum tuberosum* L.), corn (*Zea mays* L.), fertilized winter wheat (*Triticum aestivum* L.), and pea. Legumes and flax (*Linum usitatissimum* L.) are also good predecessors of buckwheat (Markov 2017).

Significant shortfalls and yield losses of a valuable cereal, honey and fodder crop – buckwheat – can be caused by numerous diseases of various etiologies. The main types of pathogens of buckwheat (Fagopyrum esculentum L.) include: peronospora blight (*Peronospora sparsa* Berk.), ascochitosis (*Peronospora fagopyri* Elenev), bacteriosis (*Pseudomonas syringae pv. syringae* (van Hall) Voung et al.), cercospora (Cercospora fagopyri Abramov), phyllosticta (*Phyllosticta polygonorum* Sacc), mosaic (*Mosaic* Buckwheat), gray rot (*Botrytis cinerea* Fr.). The main pests are: buckwheat flea (*Chaetocnema concinna* Marsh.), buckwheat weevil (*Sitona* spp.), buckwheat leaf beetle (*Oulema melanopus* Linnaeus, 1758), aphids (*Eurygaster integriceps* Puton, 1881), wheat borer (*Cnaphalocrocis medinalis* (Guenee, 1854)), thrips (*Thrips* spp.), and larvae of the Mayfly (*Chloropidae*). Depending on the degree of damage to buckwheat plants by late blight (Phytophthora polygoni Saw.), the yield loss can range from 10-20%, downy mildew (*Erysiphe polygoni* (Vaňha) Weltzien), gray rot (B. cinerea) – 20–25%, ascochyta (*Ascochyta polygoni* (Dearn. & House) Arx), bacteriosis (*Xanthomonas campestris* pv. fagopyri) – 10% and more (Markov 2017).

In the buckwheat crops of the State Farm "Skvyryska" (2022, 2023), a minimal damage to plants by pathogenic organisms of *P. sparsa*, powdery mildew (*E. polygoni*), *A. polygoni,* bacteriosis (*X. campestris pv. fagopyri*), and mosaic buckwheat was observed. Exceeding the economic threshold of harmfulness (ETH) of the main types of pathogens in the buckwheat agrocenosis was not detected. Also, the absence of pests and weeds was noted in the crops.

Sowing oats are an undemanding crop to soil fertility and predecessors. One of the determining factors in the development of oat diseases is weather conditions during ontogenesis. However, significant shortfalls in oat yield, low quality of grain and green mass cause numerous diseases, among which the most harmful are covered and flying smut, stem rust, powdery mildew, crown rust, *Septoria* spp. Reducing their harmfulness to an insignificant economic level is possible only with timely detection of diseases and careful implementation of effective preventive protective measures (Markov 2018).

Meanwhile, in the oat crops on the land plots of the State Farm "Skvyryska" (2023), a minimal damage to plants by pathogenic organisms (helmintosporiasis, striped spotting, powdery mildew, bacterial brown spotting) and pests (cereal aphid, bread aphid, Swedish midge, bread flea). However, no excess of the economic threshold (ET) of the main types of diseases and pests in oat agrocenoses was observed. A retrospective analysis of the scientific literature shows that the proper phytosanitary condition of crops is ensured by the applied agrotechnologies in compliance with crop rotation, which significantly limits the source of primary infection of many pathogens (Ivanyshyn et al. 2016; Akanmu 2021).

The main tillage should be aimed at destroying weeds, many of which are reservoirs of bacterial and viral infection, precursors and plowing (Tanchyk et al. 2020; Boincean and Dent 2019; Sun 2023). However, pesticides of different chemical action and purpose were used on the experimental field of the farm to regulate the proper phytosanitary condition and protection of crops from phytopathogenic organisms, segetal vegetation and pests. The scheme of $CPPA_S$ of crops is shown in Tables 2 and 3.

In the pea (2021), which was the predecessor of winter wheat, the $CPPA_S$ from weeds was provided by the herbicide Agritox. Its active ingredient is 2-methyl-4-chlorophenoxyacetic acid in the form of dimethylamine salt, 500 g/l). For $CPPA_S$ pea agrocenoses from a pest, the farm used a two-component contact insecticide of systemic action with repellent and acaricidal properties Fosorgan Duo (cypermethrin, 500 g/l and chlorpyrifos, 50 g/l) in the pea budding phase and the insecticide Dimephos (dimethoate, 400 g/l) in the pod formation phase. In addition, the biological preparation BioNorma inoculant, which is characterized by antagonistic properties against pathogens of mainly fungal and bacterial origin, was used for treatment of pea seeds.

Winter wheat was the predecessor of buckwheat (2021, 2022). Its seeds were treated with the fungicide Vitavax, which consisted of the following active ingredients carboxin (200 g/l) and thiram (200 g/l). Systemic herbicide Granstar Gold was used for $CPPA_S$ after germination of wheat. This herbicide consists of chemical active ingredients such as tribenuron-methyl (562.5 g/

Table 2. The scheme of $CPPA_S$ of crops in the pea – wheat winter – buckwheat crop rotation of the State Farm "Skvyra" in 2021–2023 (experiment 1)

Culture	Pesticide group	Pesticide	Amount of applied pesticide			
			Measurement units	2021	2022	2023
Peas	Herbicide	Agritox	l/ha	0.5	-	-
	Insecticide	Fosorgan Duo	l/ha	1.0	-	-
		Dimefos	l/ha	1.0	-	-
Wheat winter	Herbicide	Granstar Gold	kg/ha	-	0.025	-
	Fungicide for seed treatment	Vitavax	l/t	-	3.0	-
	Fungicide	Rex Duo	l/ha	-	0.6	-
		Tilt	l/ha	-	0.5	-
Buckwheat	Not applied.*					

Note: * not applied. – no pesticides were used in buckwheat crops (2023).

Table 3. The scheme of $CPPA_S$ of crops in the wheat winter - buckwheat - oats crop rotation of Skvyryske State Farm in 2021-2023 (experiment 2)

Culture	Pesticide group	Pesticide	Amount of applied pesticide			
			Measurement units	2021	2022	2023
Winter wheat	Herbicide	Granstar Gold	kg/ha	0.025	-	-
	Fungicide for seed treatment	Vitavax	l/t	3.0	-	-
	Fungicide	Rex Duo	l/ha	0.6	-	-
		Tilt	l/ha	0.5	-	-
Buckwheat	Not applied.*					
Oats	Herbicide	Grenadier Maxi	kg/ha	-	-	0.025
	Fungicide	Tinazol	l/ha	-	-	0.5

Note: * not applied. – no pesticides were used in buckwheat crops (2022).

kg) and tifensulfuron-methyl (187.5 g/kg). This herbicide kills both annual and perennial dicotyledonous weeds. Fungicide Tilt was used for $CPPA_S$ against pathogenic organisms (ascomycetes, basidiomycetes, deuteromycetes and etc.) that cause plant diseases. Its active ingredient is propiconazole (250 g/l). The treatment was carried out in the tillering phase – the beginning of the tube. In the phase of the beginning of earing used the fungicide Rex Duo. Its active ingredients are thiophanate-methyl (310 g/l) and epoxiconazole (187 g/l). For weed control in oats (2023), we used: Grenadier Maxi, a post-emergence highly selective herbicide, which is effective in controlling dicotyledonous weeds. For the most effective action, spraying was carried out at an early stage of weed growth in the tillering phase of plants before the tube stage. The soil-applied herbicide Grenadier Maxi consists of two components belonging to the group of sulfonylureas. This herbicide consists of the following active ingredients: tribenuron-methyl (562.5 g/kg) and tifensulfuron-methyl (187.5 g/kg). This pesticide inhibits the synthesis of enzymes and cell division in sensitive weeds within 3 hours after spraying. As a result, the development of harmful plants stops. Complete weed death is observed in 14–25 days after the application of the herbicide, depending on the type and stage of vegetation. Weeds that are less sensitive to the herbicide may not die completely, but their significant damage will reduce competition for nutrients and moisture. The highly effective fungicide Tinazol contains the active ingredient propiconazole (250 g/l). It used to protect oat leaves, stems and ears from aerial pathogens. The active ingredient propiconazole blocks the development and spread of fungal infection, disrupts the process of ergosterol synthesis in the membranes of pathogen cells.

To ensure the phytosanitary purity of buckwheat crops in weed control, the "State Register of Pesticides and Agrochemicals Permitted for Use in Ukraine" (2023) (hereinafter referred to as the State Register 2023) allows the use of

Fusilade Forte 150 herbicide with a consumption rate of 1.0–2.0 l/ha, once. This herbicide consists 150 g/l active ingredient Fluazifop-P-butyl.

At the same time, as of today (2023), no chemical disinfectants or fungicides are registered in the State Register for use on buckwheat. To disinfect the seeds of this crop, it is recommended to use one of the approved fungicidal biological products: Azotophyte (200 ml/t); Biocoplex BTU (0.5–2.5 l/t); EM1 Effective Microorganisms (0.5 l/t); Organic Balance (0.5–2.5 l/t) with the addition of trace elements (copper, boron, molybdenum, zinc salts), which improves plant development in the early stages of development, increases their productivity and resistance to infectious diseases.

However, it was found that no $CPPA_S$ products were used on buckwheat crops (2022, 2023), as only single plant damage by pests and pathogens was noted in the agrocenoses of this crop. This completely neutralized the environmental risk of exceeding the economic threshold of harmfulness of pests. The absence of weeds and pests was noted on the experimental plots of the Skvyryske farm. The purity of the crops was ensured by the biological characteristics of the varieties of buckwheat grown due to its resistance to the main types of pests, diseases and weeds inherent in this crop. At the same time, the proper phytosanitary condition of agrocenoses was ensured by the applied crop rotation. Consequently, buckwheat crops did not require the use of $CPPA_S$, primarily herbicides, insecticides and fungicides.

According to Bublyk and Krut (2022), the use of $CPPA_S$ in combination with biological products is becoming increasingly important to reduce the pesticide burden on agrocenosis. Researchers have found that the use of a mixture of fungicides with humic preparations Humifield and Fulvital Plus on winter rape crops made it possible to reduce pesticide consumption rates by 15–20%. At the same time, the combined effect of these products increased crop yields by 25–30%. On vegetable crops (white cabbage, tomatoes, cucumber), the combined use of chemical and biological products increased the effectiveness of plant protection against diseases with a 20% reduction in fungicide consumption. The combination of these means to a 13–19% increase in yields and environmentally friendly products (Bublik and Krut 2022). Therefore, in the farm "Skvyryske" for foliar feeding in the tillering phase of oats, winter wheat and peas, the microfertilizer Humifield D (0.1 kg/ha) was used. In its composition, Humifield D contains 83% of potassium salt of humic acids, which is 750 g/kg, as well as 80 g/kg of fulvic acid salt. In particular: amino acids make up 100–120 g/kg, potassium oxide (K_2O) – 100–120 g/kg, trace elements – 21 g/kg. This universal preparation is usually used for foliar feeding of plants and also for seed treatment as a growth stimulator. First of all, it provides increased plant resistance to various types of stress, stimulates the development of the root system of plants and increases root mass by up to 30%, improves the efficiency of plant nutrition from soil and fertilizers, and increases the proportion of field germination by 5–10% (Shevchuk and Didur 2019). Humifield D helps to improve the quality of soybean, grain and vegetable crops, increasing yields by up to 20% and more (Tkachuk and Shevchuk 2018). Meanwhile, Humifield D, as a growth stimulant, is used to reduce plant stress, that result from the use of pesticides, including increase drought and cold resistance of crop plants.

On oats and winter wheat, foliar fertilization was applied in the tillering phase of plants with ammonium nitrate (100 and 150 kg of physical weight/ per 1 ha, respectively). Ammonium nitrate (NH_4NO_3) contains about 35% of nitrogen in the form of ammonium (NH_4^+) and nitrate (NO_3^-) in a 1:1 ratio. This fast-acting fertilizer is well absorbed by the root system of plants and improves their nitrogen supply. Ammonium nitrate promotes the active synthesis of organic substances and proteins in plants and increases their vegetative mass of organs, while also improving the quality and yield of crops.

However, caution should be exercised when using nitrogen fertilizers, as the application of excessively high doses of nitrogen contributes to intense plant disease. At the same time, the application of balanced doses of organic and mineral fertilizers helps to increase the resistance of crop plants to pathogens such as late blight, downy mildew, cercospora, ascochyta, and others.

Assessment of ecotoxicological hazard of pesticide use in agrocenoses on research plots of the State Farm "Skvyryske" by indicators of ecotox (E)

To objectively assess the environmental hazards in the agrocenoses of the experimental field of the Skvyryske State Farm due to pesticide load in crop rotation during 2021–2023.

The aim of the study was to identify the most dangerous pesticides used for crop protection in the crop rotation of the experimental field of the Skvyra farm. Such studies will allow to eliminate or minimize the dangerous effects of toxicants in the future. The potential ecotoxicological hazard of the use of plant protection products in the experimental field was assessed. To do this, the ecotox (*E*), which characterizes the ecotoxicological hazard of pesticides, was calculated using formula (1). Calculations were made on the basis of such data as: belonging to a group of pesticides; the amount of pesticide applied; the number of treatments of each crop with pesticides during 2021–2023; ecotoxicological properties of chemical active ingredients of pesticides, etc. (table 4).

The standard for comparing ecotoxicity (*E*) for each pesticide was the ecotoxicity of DDT according to Melnikov (1987). This standard was used to assess the potential danger of pesticide contamination of agrocenoses. The most important indicators of hazardous ecotoxicological impact on the environment are the toxicity of xenobiotics, their persistence in the environment and migration capacity (Moklyachuk et al. 2017). The hazard class of each pesticide was determined according to the WHO (World Health Organization) classification. It is determined by the limiting criterion of the pesticide's harmfulness to human health. This criterion correlates with the degree of ecotoxicological hazard of the pesticide.

It has been established that the systemic post-emergence herbicides Grenadier Maxi and Granstar Gold, which have common active ingredients (tribenuron-methyl and tifensulfuron-methyl), are classified as Class III chemical hazards for humans and bees, which is formulated as a "low-hazard" substance. Instead, the systemic herbicide Agritox (2-methyl-4-chlorophenoxy-acetic acid in the form of dimethylamine salt (MCPA) used on peas (2021) belongs to the second hazard class, which is a moderately hazardous chemical. The fungicides Vitavax (carboxy and thiram), Tinazole (propiconazole), Tilt (propiconazole) and Rex Duo (epoxiconazole and thiophanate-methyl) are defined as low-hazard substances (hazard class III). At the same time, the insecticide Dimephos (dimethoate) and the insecticide Fosorgan Duo (cypermethrin and chlorpyrifos) are classified as Class II (moderately hazardous substances) according to the above classification. In Ukraine, according to the "Hygienic Classification of Pesticides by Degree of Hazard" (Sanitary and Epidemiological Norms and Regulations 8.8.1.2.002-98 Hygienic Classification of Pesticides by Degree of Hazard, 1998), pesticides are divided into four hazard classes: I – extremely hazardous; II – dangerous; III – moderately hazardous; IV – low hazardous. The criterion for the hazardousness of pesticide preparations is oral toxicity for mammals, which does not exceed LD_{50}, mg/kg body weight. The classification consists of four hazard levels: Hazard Class 1 – potent toxic substancesat which the oral toxicity is LD_{50} < 50 mg/kg, Class 2 – highly toxic, at which oral toxicity is within the limits LD_{50} from 50 to 200 mg/kg, Class 3 – moderately toxic, where LD_{50} становить from 200 to 2000 mg/kg, Class 4 – low toxic, which is in line with the toxicity LD_{50} > 2000 mg/kg. Thus, according to the hygienic classification, pesticide preparations Grenadier Maxi, Granstar Gold and Rex Duo belong to the IV hazard class – low-hazardous chemicals. The remaining products (Vitavax, Agritox, Tinazol, Tilt, Dimefos and Fosorgan Duo) correspond to Class III – moderately hazardous chemical substances.

The stability of the xenobiotic in the soil is evidenced by its half-life (DT_{50}). According to the OSU Extension Pesticide Properties Database (Vogue et al. 1994), Pesticides are divided into three classes according to their persistence: unstable pesticides (DT_{50} < 30 days), moderately stable pesticides (DT_{50} – from 30 to 100 days), and stable pesticides (DT_{50} > 100 days). In Ukraine, the persistence of pesticides in soil is assessed in accordance with the Sanitary and Epidemiological Norms 8.8.1.002-98 (1998). The evaluation is based on the following scale: I - highly persistent pesticides (DT_{50} > 60 days), II - persistent pesticides (DT_{50} - from 31 to 60 days), III - moderately persistent pesticides (DT_{50} - from 11 to 30 days), IV - slightly persistent pesticides (DT_{50} < 11 days).

Thus, active ingredients of pesticide: epoxiconazole (352 days (d.)), propiconazole (215 d.), chlorpyrifos (78 d.), and cypermethrin (68 d.) have the most stable in the soil. According to the Sanitary and Epidemiological Norms and Regulations 8.8.1.002-98, these chemicals can be classified as highly persistent pesticides in the first (I) hazard class. Other pesticides by persistence in soil belong to class III (moderately stable) and class IV – (slightly stable). The obtained results of the assessment of the danger of the use of pesticides were analyzed. It was established that the indicators of ecological danger ($E_{a.i}$) according to

Table 4. Ecotoxicological hazard of pesticides used in the experimental field of Skvyryska State Farm (2021–2023)

Pesticide	Active ingredient of pesticide	Hazard class of pesticide*	*N*, l, kg/ha	DT_{50}, (P), days/weeks	LD_{50}, mg/kg	$E_{a.i.}$, c.u.	E_P, c.u.
herbicides							
Grenadier Maxi	Tribenuron-methyl	IV	0.025	14/2.0	> 5000	$1.0 \cdot 10^{-5}$	$2.7 \cdot 10^{-5}$
	Tifensulfuron-methyl			10/1.4	> 5000	$1.7 \cdot 10^{-5}$	
Granstar Gold	Tribenuron-methyl	IV	0.025	14/2.0	> 5000	$1.0 \cdot 10^{-5}$	$2.7 \cdot 10^{-5}$
	Tifensulfuron-methyl			10/1.4	> 5000	$1.7 \cdot 10^{-5}$	
Agritox	2-methyl-4-chlorophenoxyacetic acid in the form of dimethylamine salt (MCPA DMA Salt)	III	0.5	25 /3.6	962	$1.9 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$
Fungicides							
Vitavax	Carboxylic acid	III	0.6	3/0.5	2588	$1.1 \cdot 10^{-4}$	$8.2 \cdot 10^{-4}$
	Tiram			15/2.1	> 1800	$7.1 \cdot 10^{-4}$	
Rex Duo	Epoxiconazole	IV	0.6	352/50.6	3160	$9.6 \cdot 10^{-3}$	$9.6 \cdot 10^{-3}$
	Thiophanate-methyl	III		0.6/0.1	> 5000	$0.01 \cdot 10^{-3}$	
Tinazol	Propiconazole	III	0.5	215/30.6	958	$1.6 \cdot 10^{-2}$	$1.6 \cdot 10^{-2}$
Tilt	Propiconazole	III	0.5	215/30.6	958	$1.6 \cdot 10^{-2}$	$1.6 \cdot 10^{-2}$
Insecticides							
Dimefos	Methoate	III	1.0	7 /1.0	245	$4.2 \cdot 10^{-3}$	$4.2 \cdot 10^{-3}$
Insectoacaricides							
Fosorgan Duo	Cypermethrin	III	1.0	68/9.9	286	$3.4 \cdot 10^{-2}$	$1.9 \cdot 10^{-1}$
	Chlorpyrifos			78/10.9	66	$1.6 \cdot 10^{-1}$	

Note: N - amount of applied pesticide, l, kg/ha; DT_{50} *(P)* - is the half-life of the pesticide in the soil, days/weeks; LD_{50} - is the average lethal dose for rats, mg/kg; $E_{a.i.}$ - ecological hazard of the active ingredient of pesticide, units; E_P - ecological hazard preparation of the pesticide, units; c.u. - conventional units; *Hazard class of pesticide (Regulations 8.8.1.002-98).

the active ingredient of herbicides ranged from $E_{a.i.\ tribenuron\text{-}methyl} = 1.0 \cdot 10^{-5}$ u. (Granstar Gold) to $E_{a.i.MCPA\ DMA\ Salt} = 1.9 \cdot 10^{-3}$ u. (Agritox). For fungicides, the ecotoxicity values were determined in the range from the $E_{a.i.carboxyne} = 1.1 \cdot 10^{-4}$ u. (Vitavax) to the $E_{a.i.\ propiconazole} = 1.6 \cdot 10^{-2}$ u. (Tinazol and Tilt). The highest ecotoxicity was established for the active substances of the Phosorgan Duo insecticide ($E_{a.i.chlorpyrifos} = 1.6 \cdot 10^{-1}$ u.; $E_{a.i.cypermethrin} = 3.4 \cdot 10^{-2}$ u.).

As noted earlier, the ecotox method is based on the comparison of numerical indicators of ecotoxicological hazard (*E*) of the active ingredient of pesticide preparation, with respect to the indicator of toxicity of the DDT pesticide, which is taken as a unit. Thus, it was established that the ecotoxicological hazard of using pesticides in both experiments of the Skvirske farm is 1–5 orders of magnitude lower compared to the reference standard DDT. The ecotoxicological hazard (*E*) of the Granstar Gold and Grenadier Maxi applied to cereal crops of wheat winter and oats was five orders of magnitude lower than that of DDT ($E_{Granstar\ Gold} = 2.7 \cdot 10^{-5}$ u.; $E_{Grenadier\ Maxi} = 2.7 \cdot 10^{-5}$ u.). The obtained results showed that the studied preparation is low toxic. This means that it has a low potential ecotoxicological hazard when exposed to agrocenoses. At the same time, the herbicide Agritox used on peas was characterized by a slightly higher toxicity ($E_{Agritox} = 1.9 \cdot 10^{-3}$ u.), but this indicator was also at the level of low potential ecotoxic risk of impact on crop agrocenoses.

Ecotoxicological hazard of the fungicide Vitavax is defined at the level of $E_{Vitavax} = 8.2 \cdot 10^{-4}$ u., used for the treatment of winter wheat seeds. It was four orders of magnitude lower than the benchmark DDT. The ecotoxicity indexes (E_p) for the fungicides Tinazole and Tilt ($E_{P\ Tinazole;\ Tilt} = 1.6 \cdot 10^{-2}$ u.) and fungicide Rex Duo ($E_{P\ Rex\ Duo} = 9.6 \cdot 10^{-3}$ u.), with which agrocenoses were treated wheat winter and oats for pesticidal protection against disease-causing organisms, were two to three orders of magnitude lower than that of DDT. For the insecticide Dimefos, the ecotoxicity index ($E_{Dimefos}$ = 4.2·10^{-3} units) was three orders of magnitude lower than DDT, and for the insecticide Fosorgan Duo ($E_{Fosorgan\ Duo}$ = 1.9·10^{-1} u.), the highest ecotoxicity was found for the active ingredient of the pesticide. This is only one order of magnitude lower than the toxicity of DDT. The ecotoxicological load (Σ_E) on the land plots (experiment 1 and experiment 2) was analyzed. It was calculated according to formula (2). Indicators of ecotoxicity (Ep) were taken into account for all chemical pesticides used in the crop rotation of the Skvyra research farm during 2021-2023 (Tables 5, 6).

It was established that the total weighted average pesticide load on the study area of 37 ha of experiment No. 1 during the growing seasons of 2021–2023, although not exceeding the comparison standard (E_{DDT} = 1), is quite significant ($\Sigma_{E\ experiment\ 1}$ = 0.23 c.u.) and makes possible a possible potential ecotoxicological hazard in the future land use. At the same time, the pesticide load on the land plots of 40 hectares of experiment No. 2 ($\Sigma_{E\ experiment\ 2}$ = 0.04 c.u.) indicates a low potential ecotoxicological hazard for crop agrocenoses.

Thus, the assessment of the obtained ecotoxicity values ($E_{a.i.}$) and (E_P) showed that the studied pesticides have a low potential ecotoxicological hazard of impact on crop agrocenoses. At the same time, according to the provisions of the "Hygienic Classification..." Sanitary and Epidemiological Norms and Regulations 8.8.1.2.002-98 (1998), “pesticide preparations of hazard classes III and IV may be used without restrictions, provided that the established hygienic regulations are followed”.

Thus, the results obtained indicate a low probability of ecotoxicological hazard of pesticide contamination of grain and seeds of the crops grown, which creates the prerequisites for obtaining environmentally safe grain and seed products. The research is extremely important given that the cereal crops buckwheat and oats grown at Skvyryske in 2023 are intended for sale in dietary

Table 5. Total ecotoxicological load (Σ_E) on agrocenoses of experiment 1 (fields 8, 11/4, 12) in crop rotation in 2021–2023

A year of experimentation	Crops in crop rotation	Pesticide group	Pesticide	E_p, c.u. *
2021	Peas	Herbicide	Agritox	1.9·10^{-3}
		Insecticide	Fosorgan Duo	1.9·10^{-1}
			Dimefos	4.2·10^{-3}
2022	Wheat winter	Herbicide	Granstar Gold	2.7·10^{-5}
		Fungicide - seed treatment	Vitavax	8.2·10^{-4}
		Fungicide	Rex Duo	0.9·10^{-2}
			Tilt	1.6·10^{-2}
2023	Buckwheat	-	not applied **	-
Σ_E = 0.23 c.u.				

Note: * c.u. - conventional units; ** not applied – no pesticides were used in buckwheat crops (2023).

Table 6. Total ecotoxicological load (Σ_E) on agrocenoses of experiment №2 (fields 3, 11, 15) in crop rotation in 2021–2023

A year of experimentation	Crops in crop rotation	Pesticide group	Pesticide	E_p, c.u. *
2021	Wheat winter	Herbicide	Granstar Gold	2.7·10^{-5}
		Fungicide - seed treatment	Vitavax	8.2·10^{-4}
		Fungicide	Rex Duo	0.9·10^{-2}
			Tilt	1.6·10^{-2}
2022	Buckwheat**	-	-	-
2023	Oat	Herbicide	Grenadier Maxi	1.7·10^{-4}
		Fungicide	Tinazol	1.6·10^{-2}
Σ_E = 0.04 c.u.				

Note: * c.u. - conventional units; ** - not applied – no pesticides were used in buckwheat crops (2022).

food. At the same time, it should be mentioned that even small amounts of toxic chemicals have an ecotoxicological impact on agroecosystems, which disrupts ecological connections in the agrobiocenosis through the destruction of plants, bacteria, fungi, insects, microorganisms, etc. In this regard, despite the insignificant values of ecotoxicity (E_P) compared to the DDT benchmark, it can be argued that the use of $CPPA_S$ may pose a potential environmental risk of contamination of crop agrocenoses.

However, to ensure the reliability of the hypothesis of the safety of the obtained grain and cereal products, we consider it advisable to further conduct an environmental examination of the content of pesticide residues in them to confirm their quality. This is primarily due to the need to prevent of the ecotoxicological hazard of contamination of food grain products with pesticide residues used in crop rotation on the predecessors of buckwheat and oats. After all, in order to protect human life and health from harmful factors that may be present in food, agriculture must provide the population with high-quality and environmentally safe products. It is assumed that the ecotoxicity criterion (E), which is used to assess the ecological risk of pesticide pollution of agrocenosis, can be considered as a management tool for reducing ecotoxicological hazards in agroecosystems. In particular, measures to control the use of pesticides can be part of such a mechanism to minimize their ecotoxicological hazard: limiting or banning preparations with a high degree of toxicity and persistence in the soil; replacing of $CPPA_S$ with biological; applying environmentally friendly agricultural technologies in land use, etc.

CONCLUSION

The potential environmental risk of pesticide use in the crop rotation of the experimental field of the Skvyra farm of the Skvyra Experimental Station of Organic Production of the IAEM NAAS (vegetation 2021–2023) was assessed in terms of the ecotoxic properties of pesticide active ingredients. It has been established that the main hazardous parameters of pesticides are the ecotoxicity of the active chemical (LD_{50}), the quantitative load of the toxicant on the treated area, persistence in the soil (DT_{50}), etc.

The calculations proved that, according to the indicators of ecotoxicity of chemicals - ecotoxicity (E), the pesticides used in the experimental farm had a low potential environmental risk of impact on crop agrocenoses.

It was shown that the indicators of the total weighted average pesticide load (Σ_E) on the studied land plots in the growing seasons of 2021-2023 did not exceed the comparison standard of DDT (E_{DDT} = 1): in the pea-wheat-winter buckwheat crop rotation, this indicator was $\Sigma_{E\ experiment\ 1}$ = 0.23 conventional units; in winter wheat-buckwheat-oats crop rotation – $\Sigma_{E\ experiment\ 2}$ = 0.04 c.u. The obtained results indicate an insignificant potential environmental risk of pesticide use for agrocenoses of crops of the studied farm. The low probability of ecotoxicological hazard of pesticide contamination of grain and seeds of cultivated crops creates preconditions for obtaining environmentally safe grain and seed products. However, prolonged repeated use of pesticides certainly leads to the accumulation of their residues or metabolites in the soil and can lead to contamination of crop products. In view of the fact that the cereal crops buckwheat and oats grown on the farm are intended for dietary use, further studies of their quality in terms of pesticide residues are advisable to confirm the reliability of the hypothesis of the safety of the grain and cereal products obtained.

The use of the results of pesticide load assessment on agroecosystems, taking into account the indicators of ecotoxicity, persistence of toxicants, and the ability of the territory to self-purification, can be discussed as one of the mechanisms for managing of the ecotoxicological hazard in land use to minimize the potential danger of their occurrence in agrocenoses.

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