Assessment of degradation transformations of agricultural lands

Lyudmila Zhichkina [1*], *Marina* Mirgorodskaya[2], *Kirill* Zhichkin[1], *Alexey* Marenkov[2], *Ismoil* Ergashev[2], *Alexey* Tumanov[2], and *Andrei* Volgin[2]

[1] Samara State Agrarian University, 446442 Kinel, Russia
[2] K.G. Razumovsky Moscow State University of Technologies and Management, 109004 Moscow, Russia

Abstract. The use of soil for the production of crop products leads to changes in the natural properties of soils and their natural state. When various situations arise, soil properties can change in different forms and with unequal degrees of severity; a process that worsens quantitative and qualitative properties is defined as soil degradation. The significant role of soil in people's lives should serve as an incentive for its rational use and to prevent the occurrence of degradation transformations leading to a decrease in its environmental and production functions. The purpose of the research is to assess soil contamination of agricultural lands in the Samara region with insecto-acaricides and herbicides. Objectives: - to establish the average and maximum content of residual quantities of pesticides in soils; - determine the area of contamination with residual quantities of pesticides. The research was carried out in 7 districts (Bezenchuksky, Syzransky, Stavropolsky, Volzhsky, Privolzhsky, Bolshechernigovsky, Elkhovsky) of the Samara region in 2020-2022. To assess soil contamination with residual amounts of pesticides, soil samples were taken in spring and autumn to the depth of the arable layer. In selected soil samples, the residual amount of insectoacaricides (DDT, HCH, HCB, metaphos) and herbicides (prometrin, atrazine, simazine, 2.4-D, trifluralin, THAN, dalapon) was determined. The analysis of contamination of agricultural land in the study region showed that the content of controlled pesticides in soils depended on both the period of soil sampling and the year of research.

1 Introduction

In modern conditions of agricultural production, problems arise associated with anthropogenic impact and global changes in climatic conditions. Significant areas of agricultural land are subject to degradation transformations. Natural and anthropogenic degradation processes can occur on a global, regional and local scale. Identification of the causes, conditions and factors determining their development on agricultural lands serves as a reserve for increasing soil fertility and the productivity of cultivated crops [1-6].

* Corresponding author: zhichkinaln@mail.ru

Fertility is an important characteristic of agricultural land. The soil is considered fertile if it satisfies the needs of specific plants for nutrients, water, air and heat. Each component is important and irreplaceable. However, a group of specific organic soil compounds – humus – stands out. A lack or excess of the components of fertility reduces the productivity of agricultural crops [7-10].

Soil is a complex multifunctional system, which is currently an irreplaceable natural resource from the point of view of its use as a means of agricultural production. This is a relatively renewable resource, since as soil resources are used, they are constantly restored, however, the recovery period is quite long [11-13].

Soil performs a number of ecological functions (ecosystem and global) and a production function, determining the environmental and economic well-being of humanity. Being part of any terrestrial biogeocenosis, it is subject to various types of degradation processes [14].

Landscape degradation manifests itself in negative changes, expressed in a decrease or loss of the ability to perform the functions of reproduction of resources and the environment, as well as socio-economic ones. In the context of anthropogenic transformation of landscapes, soil degradation is considered, understanding by it the steady deterioration of their properties and regimes, which have a direct impact on changes in environmental and production functions [15-18].

Degradation processes in soils can occur under the influence of natural and anthropogenic factors, while human influence can lead to a more intense manifestation of natural factors. The variety of forms of manifestation of degradation processes (degumification, erosion, waterlogging, salinization, pollution, etc.) can be divided into three categories: physical, chemical and biological degradation. Physical degradation of soils leads to deterioration of the structure, an increase in its density, a decrease in water permeability and a deterioration in the water-air regime of soils, which can further contribute to the destruction of the soil profile and makes it impossible to perform such ecological functions as living space, housing and shelter for living organisms living in the soil. soil and remaining in it. Chemical degradation of soils is associated with a decrease in reserves of humus and other nutrients, changes in the reaction of the environment and redox potential, secondary salinization, salinization, and pollution. Chemical degradation processes affect the nutritional regime of the soil, biochemical and physicochemical processes, thereby affecting environmental and production functions. Biological degradation leads to a reduction in the species diversity of living organisms and a deterioration in the sanitary condition of the soil. This may be due to the accumulation of phytotoxic substances and a reduction in vegetation cover. A consequence of degradation transformations in natural and agricultural landscapes may be a decrease in soil fertility, which reduces the food resources of the biosphere [19-22].

Natural biogeocenoses are more resistant to the occurrence of degradation processes, since their existence occurs due to a complex of natural mechanisms (biological cycle of substances, large species diversity, significant reserves of organic matter, etc.). Unlike natural biogeocenoses, agrocenoses function in a mode set by man, who must maintain certain production functions without reducing environmental functions. Agrocenoses are characterized by less stability, since they are focused on productivity and a certain quality of products, therefore agricultural technologies must be adapted to a specific natural landscape, which will reduce the likelihood of degradation processes occurring [23-25].

Modern cultivation of agricultural crops involves the use of pesticides of different compositions and objects of application. All pesticides used as a means of controlling pests, diseases and weeds are more or less toxic to animals and humans. In addition, they have a negative effect on beneficial organisms living in the soil. The widespread use of pesticides increases the risk of pollution of the biosphere and soil cover as its integral part. Once in

the soil, pesticides undergo various chemical transformations and can become fixed and remain in the soil for a long time, leading to its pollution [26].

Currently, there is no option to stop using pesticides. However, the rational use of pesticides (optimization of timing and methods of application; selection of drugs characterized by less toxicity; reduction in the number of treatments, etc.) and constant monitoring of the content of their residues in water, air and soil will help prevent negative consequences. Contamination of agricultural lands with pesticides refers to chemical degradation of soils.

2 Materials and methods

The purpose of the research is to assess soil contamination of agricultural lands in the Samara region with insecto-acaricides and herbicides. Objectives: - to establish the average and maximum content of pesticide residues in soils; - determine the area of contamination with residual quantities of pesticides.

The studies were carried out in districts of the Samara region in 2020-2022. Soil samples were taken twice a year (spring and autumn) in accordance with RD 52.18.697 (Observations of residual amounts of pesticides in environmental objects. Operation and procedure) and RD 52.18.156-1999 (Nature conservation. Soils. Sampling methods combined soil samples and assessment of agricultural land contamination with pesticide residues) [27-30].

In the spring, soil sampling was carried out after the snow melted before the use of pesticides, in the fall - after harvesting. Single samples were taken to the depth of the arable horizon. The pooled sample was compiled by mechanically mixing 10 single samples. The mass of the combined sample is not less than 1 kg. [31]

In soil samples, the residual amount of insectoacaricides (organochlorine - DDT (dichlorodiphenyltrichloroethane) and its metabolites; HCH isomers (hexachlorocyclohexane) - alpha, beta and gamma; HCB (hexachlorobenzene); organophosphorus - metaphos) and herbicides (triazine - prometrin, atrazine, simazine; 2.4-D (2.4-dichlorophenoxyacetic acid); trifluralin; THAN (sodium trichloroacetate); dalapon) [32-34].

The main criterion for the ecological state of soils in the Russian Federation is the MPC (maximum permissible amount) and UPC (approximately permissible amount) of harmful substances. Hygienic standards establish the maximum permissible levels of active substances of pesticides and their hazardous metabolites in the environment. The contaminated category according to GOST 17.4.3.04-85 (Nature conservation. Soils. General requirements for control and protection from pollution) includes soils in which the amount of pollutants exceeds the MPC or APC [35].

For determined residual amounts of pesticides, the MPCs are: total DDT, total HCH, metaphos, 2.4-D – 0.1 mg/kg; simazine – 0.2 mg/kg; prometrin, atrazine, dalapon – 0.5 mg/kg; The ADCs are: HCB – 0.03 mg/kg; trifluralin – 0.1 mg/kg; THAN – 0.2 mg/kg [36].

3 Results

In 2020, studies on the content of pesticide residues in the soils of the Samara region were carried out in the Bezenchuksky, Syzransky, Stavropolsky and Volzhsky districts; a total of 1711.1 hectares of agricultural land (23 fields) were examined. In 2021, the residual amount of pesticides in the soil was determined in the Bezenchuksky, Syzransky, Privolzhsky, Bolshechernigovsky and Volzhsky districts, the total survey area was 1414.0 hectares (18 fields). In 2022, 1580.0 hectares of agricultural land (15 fields) in Bezenchuksky, Syzrankiy, Privolzhsky, Elkhovsky, Bolsheglunitsky and Volzhsky districts

were examined for the content of pesticide residues. Thus, over 3 years, 4705.1 hectares of agricultural land were surveyed [37, 38].

The land fund of the Russian Federation, according to state registration data as of January 1, 2023, amounts to 1,723,399.1 thousand hectares, excluding internal sea waters and the territorial sea; agricultural lands occupy 22.1% of the total area of the land fund (Table 1). The area of the land fund of the Samara region is 5356.5 thousand hectares, of which agricultural lands occupy 75.9% of the area [39-41].

Table 1. Land Fund of the Russian Federation and Samara Region.

Index	Meaning
Area of the land fund of the Russian Federation, thousand hectares	1723399.1
including agricultural land, thousand hectares	379134.7
Area of land fund of the Samara region, thousand hectares	5356.5
including agricultural land, thousand hectares	4066.4

In pursuance of Russia's international obligations under the Stockholm Convention on Persistent Organic Pollutants, annual monitoring of the content of residual quantities of the banned pesticide, DDT, in the soil is carried out in the Samara Region. The survey area for the content of total DDT and HCH was the most extensive of all the pesticides determined [42-44]. In 2020, it was 782 hectares (in spring) and 889 hectares (in autumn); in 2021 677 hectares and 737 hectares; in 2022, 710 hectares and 870 hectares, respectively.

The average and maximum content of total DDT in the soil of all farms in the region in the spring corresponded to hygienic standards and varied over the years from 0.003 mg/kg (2020) to 0.006 mg/kg (2021) and from 0.03 MPC (2022) up to 0.5 MPC (2021). The residual amount of total HCH was lower than that of total DDT and was observed only in 2020 - 0.34 MPC and in 2021 - 0.11 MPC. An analysis of the HCB content in soils showed that the maximum content in spring did not exceed 0.1 MPC (2021). In the surveyed area in the spring, there was a decrease in the content of metaphos in the soil in 2020: 0.002 mg/kg, in 2021, 0.001 mg/kg in 2022 was not detected (Table 1).

Herbicide 2.4-D is widely used to control weeds during the cultivation of agricultural crops. The highest average content of 2.4-D was observed in the soil in 2020 – 0.067 mg/kg, the lowest in 2022 – 0.028 mg/kg. Exceeding the maximum permissible concentration was not observed. The herbicide dalapon is not approved for use in Russia, but its presence is noted in the soil every year. So in 2020 the maximum content was 1.29 MPC, in 2021 – 0.84 MPC, in 2022 – 0.21 MPC. At the same time, there is a tendency to reduce the residual amounts of dalapon in the soil. Residue amounts of prometrin were detected only in 2020 (0.017 mg/kg) and in 2022 – 0.032 mg/kg.

Table 2. The content of residual amounts of pesticides in the soil in spring.

Controlled pesticide	2020		2021		2022	
	average content, mg/kg	maximum content in units of MPC, UPC*	average content, mg/kg	maximum content in units of MPC, UPC*	average content, mg/kg	maximum content in units of MPC, UPC*
Insectoacaricides						
Amount of DDT	0.003	0.34	0.006	0.50	0.000	0.03
Amount of HCH	0.000	0.34	0.001	0.11	0.000	0.00
HCB*	0.000	0.07	0.000	0.10	0.000	0.03
Metaphos	0.002	0.28	0.001	0.05	0.000	0.00
Herbicides						

2.4-D	0.067	0.89	0.047	0.59	0.028	0.90
Dalapon	0.307	1.29	0.316	0.84	0.054	0.21
Prometrin	0.017	0.26	0.000	0.00	0.032	0.20
Simazine	0.056	0.92	0.019	0.42	0.054	1.61
Atrazine			0.001	0.00	0.006	0.04
Trifluralin*	0.010	0.19	0.003	0.17	0.000	0.04
THAN*	0.000	0.02	0.023	0.21	0.081	0.65

Simazine and atrazine are not approved for use; however, their residual amounts were encountered annually in the soil during the years of research in the spring [42]. In 2022, the maximum content of simazine over the years of research was noted - 1.61 MPC, while anthrazine in the soil was significantly lower, the highest value being 0.04 MPC (2022). Trifluralin was observed in soil in small quantities annually. The highest average content in spring was 0.010 mg/kg (2020). The highest average content of TCAN was detected in 2022: 0.081 mg/kg (0.65 MPC).

Thus, the average and maximum content of residues of most of the studied pesticides in the soil in 2020-2022 in the spring it complied with hygienic standards. The exceptions were the herbicides dalapon (2020) and simazine (2022), their maximum content exceeded the MPC.

Herbicides and insectoacaricides are used throughout the entire growing season of agricultural crops [43-47]. A significant proportion of the substances that make up pesticides settles on plants, but some of them can remain on the surface and in the soil, leading to its contamination. In the fall of 2020, the maximum content of total DDT in soil samples was 1.16 MPC, in 2021 – 0.11 MPC, in 2022 – 0.02 MPC. The residual amount of total HCH was observed in 2020-2021 and was insignificant (0.03-0.04 MPC). Determination of HCB in soil showed that the maximum content was detected in 2020 and amounted to 0.33 MPC. The residual amount of metaphos in soil samples did not exceed the MPC; the maximum content was observed in 2021 – 0.92 MPC (Table 3).

Table 3. The content of residual amounts of pesticides in the soil in autumn.

Controlled pesticide	**2020**		**2021**		**2022**	
	average content, mg/kg	**maximum content in units of MPC, UPC***	**average content, mg/kg**	**maximum content in units of MPC, UPC***	**average content, mg/kg**	**maximum content in units of MPC, UPC***
Insectoacaricides						
Amount of DDT	0.005	1.16	0.001	0.11	0.000	0.02
Amount of HCH	0.000	0.04	0.000	0.03	0.000	0.00
HCB*	0.000	0.33	0.000	0.20	0.000	0.00
Metaphos	0.006	0.40	0.010	0.92	0.000	0.00
Herbicides						
2.4-D	0.027	0.42	0.010	0.17	0.086	1.51
Dalapon	0.307	0.70	0.422	1.16	0.096	0.40
Prometrin	0.000	0.02	0.001	0.03	0.003	0.04
Simazine	0.037	0.77	0.000	0.00	0.011	0.30
Atrazine			0.004	0.11	0.023	0.65
Trifluralin*	0.007	0.20	0.013	0.80	0.010	0.30
THAN*	0.000	0.04	0.036	0.64	0.075	0.49

The average content of 2.4-D residues during the years of research varied from 0.010 mg/kg (2021) to 0.086 mg/kg (2022). The maximum content in 2022 exceeded the MPC. The herbicide dalapon was observed in soils annually. The highest average and maximum content was in 2021 – 0.422 mg/kg and 1.16 MPC, respectively. Triazine herbicides prometrin, simazine, and atrazine were found annually in the soils of the survey sites. The maximum content of prometrin, simazine and atrazine was observed in 2022: 0.04 MPC, 0.30 MPC and 0.65 MPC, respectively. Residues of trifluralin were detected in all years of study. The highest maximum content of trifluralin in the soil was observed in 2021 (0.80 MPC). The pesticide THAN was found in soil samples every year. The annual maximum was observed in 2021. 0.036 mg/kg is the average content, 0.64 MPC is the maximum content.

During the research, it was found that the average and maximum content of residual quantities of most of the studied pesticides in the soil in the fall in 2020-2022 complied with hygienic standards. The exceptions were the insectoacaricide DDT (2020) and herbicides 2.4-D (2022), dalapon (2021), their maximum content exceeded the MPC.

Examination of soils for the content of residual quantities of pesticides revealed the following patterns. In the fall of 2020, the maximum content of total DDT in soil samples exceeded the MPC. The content of residual amounts of total HCH was insignificant (0.04 MPC) and complied with the established standards. The content of the insectoacaricide HCB in the soil was low, the annual maximum was 0.33 MPC (autumn). There was an increase in the maximum metaphos content in the autumn to 0.4 MPC. The content of herbicides 2.4-D, dalapon, simazine, atrazine and prometrin in the soil in the spring was higher than in the autumn. The maximum level of residual amounts of dalapon in the spring exceeded the MPC. The content of the herbicides trifluralin and THAN in the soil increased by autumn, but did not exceed the established standards.

The residual amount of total DDT in 2021 was more often observed in samples taken in the spring, decreasing to zero values by the fall. The residual amount of total HCH was lower than that of total DDT in both the spring and autumn periods. Analysis of the HCB content in soils showed that the maximum content in the spring did not exceed 0.1 MPC, increasing by autumn to 0.2 MPC. In the surveyed area in the autumn, the content of metaphos in the soil increased to 0.010 mg/kg. The content of herbicides 2.4-D and simazine in the soil was higher in spring than in autumn. The content of residual amounts of the herbicides dalapon, prometrin, atrazine, trifluralin and THAN was higher in the autumn period. The maximum amount of dalapon herbicide in the fall exceeded the MPC.

In 2022, total DDT was determined in soil samples in the spring (0.03 MPC) and autumn periods (0.02 MPC), HCB was 0.03 MPC and was noted only in spring. No total HCH and metaphos were detected. The maximum content of the herbicide 2.4-D (in autumn) and simazine (in spring) exceeded the MPC. The content of dalapon, atrazine and trifluralin in the soil increased in autumn and amounted to 0.096 mg/kg, 0.023 mg/kg and 0.010 mg/kg, respectively. The content of the herbicides prometrin and THAN decreased by autumn.

In 2020-2022 Contaminated areas that did not meet hygienic standards were identified on the territory of the Samara region. An analysis of soil contamination with herbicides in the spring of 2020 showed that the maximum dalapon content was 1.29 MPC. The total survey area is 109 hectares, the area of contamination is 8.0 hectares (7.3%). In the fall of 2020, the maximum level of total DDT was 1.16 MPC. The total survey area was 889 hectares, the area of contamination was 14.2 hectares (1.6%) (Table 4).

Table 4. Maximum content of controlled pesticides exceeding MPC.

Controlled pesticide	Year	Surveyed area, ha	Soil sampling period	Contaminated area, ha
Insectoacaricides				
Amount of DDT	2020	889	autumn	14.2
Herbicides				
Dalapon	2020	109	spring	8.0
	2021	107	autumn	34.0
2.4-D	2022	126	autumn	61.5
Simazine	2022	108	spring	8.4

In the autumn of 2021, soil contamination with residual amounts of the herbicide dalapon (1.16 MPC) was detected. The survey was carried out on an area of 107 hectares, the area of contamination was 34 hectares (31.8%). In the spring of 2022, an increased content of simazine in the soil was established (1.61 MPC). The surveyed area was 108 hectares, contamination was found on an area of 8.4 hectares (7.8%). In the fall of 2022, the herbicide 2.4-D caused soil contamination (the maximum was 1.51 MPC). The total survey area is 126 hectares, the area of contamination is 61.5 hectares (48.8%).

4 Conclusion

Currently used pesticides can lead to chemical contamination of agricultural land. Chemical contamination of soil with residual quantities of pesticides is regulated by regulatory documents at the state level, which makes it possible to record and control contamination. Studies have shown that in the soils of the Samara region under crops of field and fruit crops there are residual amounts of pesticides, both currently used (metaphos, trifluralin, 2.4-D, prometrin), and the use of which is currently not permitted (DDT, HCH , HCB, dalapon, simazine, atrazine, THAN). During the years of research, the maximum content of the insectoacaricide DDT (2020), herbicides: dalapon (2020, 2021), 2.4-D (2022), simazine (2022) exceeded the MPC. The area of contamination was 22.2 hectares in 2020, 34.0 hectares in 2021 and 69.9 hectares in 2022. When soil contamination is above the maximum permissible concentration (MPC), it is necessary to analyze the causes of pollution and try to eliminate them by reducing the pesticide load (reducing the amount treatments, replacement of chemicals with biological ones, etc.). The average content of residual quantities of controlled pesticides in the studied soils of the Samara region complied with hygienic standards.

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