Hazard assessment of pesticides’ application in agroecosystems

I V Slastya*

Russian State Agrarian University, Moscow Agricultural Academy named after K.A. Timiryazev, 127550 Moscow, Russia

* E-mail: slastya@rgau-msha.ru

Abstract. The danger assessment of using pesticides and the effectiveness of reducing the pesticide load in agroecosystems of grain crops and fodder beet according to the indicators of predicted pollution and agro-eco-toxicological index (AETI) was carried out. A significant decrease in the predicted agroecosystems' contamination indicators with pesticides and AETI was found with a decrease in the fungicides consumption rates by 50% and insecticides by 20% when combined with silicon compounds. The comparison of indicators of predicted pollution and AETI for grain crops agroecosystems in different natural and climatic zones was carried out. The greatest danger is the use of pesticides in the dry-steppe zone of chestnut soils due to their low self-cleaning ability.

1. Introduction

Currently, the chemical method of pest control, diseases, and weeds of agricultural crops is the leading one in world agriculture, which is due to its high economic efficiency. However, the use of pesticides poses a high risk not only for harmful organisms, but also for humans, other representatives of fauna and flora; therefore, a particularly important role is assigned to the regulation of their use in agriculture.

The regulation of pesticides' use is based on the quantitative assessment of their danger and content rates in environmental objects and agricultural products based on toxicological and hygienic criteria mainly aimed at ensuring human safety. These criteria do not fully consider the dangers of pesticides for beneficial flora and fauna, natural ecosystems in general. For a comprehensive assessment of pesticides' hazard to the environment, it was proposed to use ecological and toxicological criteria; in addition to toxicity for warm-blooded and persistence in the soil, they also include consideration of pesticide effect on soil enzymatic processes and biota, migration along the soil profile, translocation into cultivated plants and impact on crop quality, impact on the organoleptic properties of food and water, phytotoxicity, susceptibility to photodegradation, volatility [1]. Sokolov M.N. and Strekozov B.S. proposed an approach consisting in a point assessment of each of eleven proposed indicators according to their proposed scales and determining the pesticides' hazard class by the total of points (with a total of more than 21 points, pesticides are classified as dangerous, 14-21 - medium hazard, up to 14 - low hazard) [1]. According to other authors [2, 3], despite a sufficiently large number of considered indicators, this approach still did not sufficiently reflect the pesticides' danger to human health.
Vasiliev V.P., Kavetsky V.N. and Bublik L.I. [2, 3] proposed to assess pesticides danger on the basis of four ecological and toxicological indicators, two of which characterize a pesticide's danger to humans to the greater extent (category A) - the average lethal dose when administered into the stomach ($LD_{50}$) (the main indicator) and the coefficient of functional cumulation ($C_{cum}$); the other two – pesticide's hazard to the environment (category B) – resistance in the soil ($T_{50}$ – half-life for non-toxic components (the main indicator) and the average lethal concentration for fish ($AC_{50}$). Based on these criteria, they proposed an ecological and toxicological classification of pesticides including four hazard classes, as well as a method for assessing the danger of using pesticides and predicting agroecosystems' pollution in specific soil and climatic conditions.

There are known approaches to assessing the hazard of pesticides based on their hazard for indicator non-target species [4]. Due to high pesticides' toxicity for aquatic organisms, methods for assessing their danger only to aquatic organisms based on their ranking by the value of the average lethal concentration, the maximum inactive concentration (NOEL) and the bioaccumulation coefficient were also proposed [5, 6]. Some approaches to determining pesticides' hazard are based on assessing the risk of their application using not only indicators of toxicity, persistence, bioaccumulation, but also the predicted substance concentration in the environment and the consumption level [5-8]. Mathematical models are used to predict the pesticides' concentration in surface reservoirs [5, 6] and soil with an assessment of the pesticides' risk degree for soil, air, surface, and groundwater [9]. Despite a variety of methodological approaches to assessing the dangers of using pesticides, there is currently a weak "convergence" between them [10].

2. Materials and Methods

In this work, the methodology of Vasiliev V.P., Kavetsky V.N. and Bublik L.I. [2, 3] was used to determine the indicators of predicted pollution ($V$) of agroecosystems and the agro-eco-toxicological index of pesticide use for the traditional zonal system of plant protection products' application and the technology proposed by the authors. The proposed technology lies in the use of fungicides reduced by 50% and insecticides reduced by 20% when used together with silicon compounds (tetraethoxysilane (TES) and sodium silicate).

Field experiments to study the effect of silicon compounds on the pesticides' effectiveness and the possibility of reducing their consumption rates were conducted in 1994-1998 and 2005-2007 in Moscow and Volgograd regions. TES and sodium silicate are a film-forming agent and an adhesive, respectively; they were used at a concentration of 0.4% in tank mixtures with pesticides. The hazard assessment of pesticides' application was carried out on the example of grain crops' agrocenoses cultivated in most regions of the Russian Federation: spring and winter wheat, spring barley, fodder beet – for the conditions of the Moscow region (zone of sod-podzolic soils).

The pesticide's hazard degree is determined based on a combination of ecological and toxicological indicators of two categories A and B according to the following formula [3]:

$$D_0 = (C_A + C_B) - 1,$$

where $D_0$ - pesticide's hazard degree,

$K_A$ - hazard class as of category A,

$K_B$ - hazard class as of category B.

Depending on the value of the $D_0$ indicator, which can take values from 1 to 7, pesticides are characterized by the hazard degree as very dangerous (1 and 2), dangerous (3), moderately dangerous (4 and 5) and low risk (6 and 7).

The weighted average hazard degree of pesticides ($D_{wa}$) used in agriculture can be determined by the formula:

$$D_{wa} = D_1 m_1 / M_1 + D_1 m_2 / M_2 + D_1 m_3 / M_3 + ... + D_n m_n / M_n,$$

where $D_{wa}$ is the hazard degree of the pesticide;
m – pesticide's mass, kg;
M - the total mass of pesticides used in the territory, kg.

The average pesticides' load on the territory is characterized by an ecotoxicological dose \( D_{\text{ect}} \), \( \text{kg/ha} \) determined by the formula:

\[
D_{\text{ect}} = \frac{M}{S},
\]

where \( S \) is the total arable area (ha).

The landscape stability to the pesticide load is determined by the self-cleaning ability of soils, which characterizes the intensity of pesticides' destruction depending on soil and climatic conditions and is expressed by the index of self-cleaning ability \( I_{\text{sc}} \) taking values from 0.1 to 1 \[11\].

For regions with very intense self–cleaning ability \( I_{\text{sc}} \) - greater than 0.80; intense – 0.80–0.61; moderate – 0.60–0.41; weak – 0.40–0.21, very weak – 0.20 or less. For the zone of sod-podzolic soils and floodplain soils, \( I_{\text{sc}} \) is equal to 0.50; for the zone of ordinary chernozems and gray podzolic soils – 0.6–0.7; for the steppe sub-zone of ordinary chernozems - 0.4–0.5; for the steppe sub-zone of southern chernozems – 0.3–0.4; for the dry-steppe zone of dark chestnut and chestnut soils – 0.2–0.3.

The indicator of predicted pollution \( (V) \) is used to assess the danger of landscape pollution with pesticides. It considers the weighted average degree of pesticides hazard, ecotoxicological dose and the index of soil self-cleaning ability; it is determined by the formula:

\[
V = \frac{D_{\text{ect}}}{D_{\text{wa}}} I_{\text{sc}},
\]

The level of potential danger to ecosystems when applying pesticides can be characterized by an agro-eco-toxicological index (AETI) determined by the formula:

\[
AETI = \frac{10V(1+V)^3}{(1+V)^4 + 5000},
\]

With an AETI value from 0 to 1, the level of territory's contamination with pesticides is low–risk, from 1 to 4 – medium-risk, from 5 to 7 – elevated-risk and from 8 to 10 – high-risk.

3. Results and discussion
The most effective way to reduce the pesticide load and the danger of using pesticides for ecosystems is to reduce the consumption rates of the used preparations, provided that their biological activity is preserved. One of the ways to reduce the preparations' consumption rates is the use of additive agents that increase the pesticides' efficiency, including significantly reducing the loss of preparations. Additive agents include various adhesives and film-forming agents; some of them have their own biological activity. The studies have shown that TES and sodium silicate have contributed to increasing the plants' resistance to adverse factors: diseases and pests, moisture deficiency (drought) \[12, 13, 14\]. The use of selenium compounds is also promising; those increase both the productivity of plants and their resistance to stress \[15, 16\]. Combined use of silicon compounds with pesticides allowed to reduce the consumption rates of fungicides by 50%, insecticides - by 20% without reducing the effectiveness of protective equipment \[12, 13, 14\].

The environmental hazard of the most used range of chemical plant protection products including seed protectants, fungicides and herbicides used during the growing season was assessed for different soil and climatic zones with different tolerance to pesticide load depending on the soils' ability to self-cleaning. The hazard assessment of pesticides' application used in the recommended consumption rates and reduced by 20% (insecticides) and 50% (fungicides) together with silicon-containing substances was carried out according to the indicators of predicted pollution \( (V) \) and AETI.
Table 1. Hazard assessment of the used pesticides' range in various soil and climatic zones

| Plant protection system | Predicted pollution V, cond. kg/ha | AETI | Environmental hazard level |
|-------------------------|-----------------------------------|------|----------------------------|
|                         | Fodder beet                       |      |                            |
|                         | Zone of sod-podzolic soils         |      |                            |
| Zonal                   | 1.88                              | 0.09 | low hazard                 |
| Proposed                | 1.22                              | 0.03 | low hazard                 |
|                         | Cereals                           |      |                            |
|                         | Zone of sod-podzolic soils         |      |                            |
| Zonal                   | 3.40                              | 0.54 | low hazard                 |
| Proposed                | 2.56                              | 0.22 | low hazard                 |
|                         | Forest-steppe zone of typical chernozems and gray forest soils |      |                            |
| Zonal                   | 2.83                              | 0.30 | low hazard                 |
| Proposed                | 2.13                              | 0.13 | low hazard                 |
|                         | Steppe sub-zone of ordinary and southern chernozems |      |                            |
| Zonal                   | 4.25                              | 1.07 | medium hazard              |
| Proposed                | 3.20                              | 0.45 | low hazard                 |
|                         | Dry-steppe zone of chestnut soils  |      |                            |
| Zonal                   | 8.50                              | 5.24 | elevated hazard            |
| Proposed                | 6.41                              | 3.25 | medium hazard              |

The research results have shown that the hazard degree of agricultural landscapes' contamination in the sod-podzolic soils' zone is low, while the predicted pollution is twice as high for agroecosystems of grain crops rather than for fodder beet. The AETI value for grain crops' agroecosystems is 6-7 times greater than for fodder beet. Reducing the consumption rates of fungicides and insecticides when using silicon compounds made it possible to reduce the predicted contamination of grain crops' agroecosystems by 1.5 times, fodder beet - by 1.3 times, AETI - by 3.5 and 2.4 times, respectively.

The considered hazard indicators of using pesticides in grain crops’ agroecosystems in different soil and climatic zones are different: the lowest values of the predicted pollution and AETI are characteristic of the forest-steppe zone of ordinary chernozems and gray forest soils due to their high self-cleaning ability. In the steppe sub-zone of ordinary and southern chernozems, the indicators of predicted pollution and AETI are increasing and the hazard level of applying pesticides when using zonal technology becomes medium hazard, while the proposed one remains low hazard. In the dry–steppe zone of chestnut soils, the hazard level of pesticides' application increases to elevated with zonal technology and moderate (medium hazard) with the recommended one.

The indicators of predicted pollution and AETI in all the considered zones are lower when using pesticides at reduced consumption rates together with silicon compounds compared to zonal technologies. It is especially important to reduce the consumption rates of pesticides in areas with low self-cleaning soil ability and tolerance to pesticide load. Thus, this method made it possible to assess the danger of using pesticides for the environment and the effectiveness of reducing the pesticide load on agroecosystems in various soil and climatic conditions.

4. Conclusions
1. In the zone of sod-podzolic soils, the predicted pesticide contamination of agricultural grain crops was twice as high, and the AETI was 6-7 times higher than that of fodder beet.
2. The use of the proposed technology allowed to reduce the predicted pollution of grain crops' agroecosystems by 1.5 times, fodder beet – by 1.4 times, AETI – by 3.5 and 2.4 times, respectively.
3. The contamination hazard degree of agricultural landscapes in the zone of sod-podzolic soils and the forest-steppe zone of typical chernozems and gray forest soils is low. The greatest danger is the use of pesticides in the dry-steppe zone of chestnut soils due to their low self-cleaning ability.
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