The complex analysis of the “soil-plant” system stability to multicomponent herbicides

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Abstract. With the aid of the system analysis elements we identified type and subsystem "soil-plant" reaction orientation under the influence of the disturbing effect of herbicides. It is established that subsystem "soil" is distinguished by "accidental" type of management, smaller connectivity between elements and smaller rigidity in comparison with subsystem "plant".

In an ecological system the basis of its life support is made up by the soil and plants connected with each other both directly and indirectly. In their turn they are the subsystems formed by a set of simpler elements with their own properties. According to the principles of system ecology system properties do not come down to the sum of properties of its elements. In the majority of research works on agroecosystems functioning their individual components in a number of the parameters are researched, analyzed, as a rule, without regard to their complexity.

In our work we consider the system consisting of two biological subsystems - "soil" and "plant". From positions of system approach these objects can be subdivided into corpuscular (discrete) and "rigid" systems, conditionally.

Besides, the subsystems investigated by us can be divided into two types, depending on differences in their behavior regulation [1]: the biological systems of p-type with "passive" control and r-type with "accidental" control [2].

It is possible to judge about systems stability by a measure of the set properties deviation caused by the disturbing measure of external influence. Such approach allows to take as a basis for quantitative estimates of stability the estimates juxtaposition characterizing, on the one hand, a measure of the disturbing influences and, on the other – the caused measure of deviations of the set properties from the norm.

In 2011-2012, experiments started on influence of multicomponent herbicides on the "soil-plant" system. As a model object there was used the field with crops of spring-sown wheat of a variety Altayskaya 70. As the disturbing factor there acted crops treatment by agents: Turbo secateurs (hereinafter Secateurs), Puma Super (hereinafter Puma) and their tank mixture (hereinafter P+ S), manufacturer Bayer AG, Germany. Herbicides were used in the doses recommended by the manufacturer. The soil on pilot sites – the chernozem ordinary.

For the complex analysis of a system behavior we used the following indicators. On enzymatic activity of the soil (enzymes - the catalase, urease, protease, – polyphenol oxidase (hereinafter PO)), ascorbate oxidase) there was established the mediated influence of xenobiotics on stability of a subsystem "soil". By means of biological efficiency indicators of plants there was found out the
influence of pollutant on a subsystem "plant". Data on absolute measures are published in the articles [3.4]. For systematization of the obtained results and complex study of the system "soil-plant" there was applied the factorial analysis, a method of correlation counts [5], indexes of enzymatic activity of the soil (IEA) and biological efficiency of cultural plants (BEI) and determination of a system rigidity [7]. As the software there are used the Package of the analysis MS Excel and Stat Soft STATISTICA 6.0.

The factorial analysis allowed us to find out changes in the "soil-plant" system in general. To estimate similarity and distinctions of test options, we applied the discriminant analysis which revealed the most informative indicators.

By results of this analysis we constructed the graph of two-dimensional distribution of test options enzymatic activity of soil samples and biological efficiency of plants in space of discriminant functions (figure 1a and 1b).

As can be seen from figure 1a, all test options differ from checks on the axis Root 1. Dots corresponding to a check are situated in the center of the variation field in the positive area on the common scale Root 1. To the left of the center of the variation field there are located dots belonging to the option with the tank mixture and middle values of Root 1 are negative, to the right – dots corresponding to the option with Puma and middle values of Root 1 are positive. Dots corresponding to the option with Secateur are in the negative zone as related to the scale Root 1 and take the central position in the variation field. From here it is seen that herbicide options are situated at approximately the same distance from the common center of variation field on the scale Root 1.

![Gráfico 1](image1.png)

**Figure 1.** Distribution of the test options of the soil layer 0-15 cm by ferment activity and by biological efficiency indicators in the space of the first and second discriminant functions.

To the right on the axis Root 1 there are options with the low protease, PO, catalase activity but with high activity of ascorbate oxidase and urease. To the left on the axis Root 1 there are options with the high fermentative activity of protease, PO, catalase but with low activity of ascorbate oxidase and urease.

The biggest contribution into the difference between check and test options was made by ascorbate oxidase, protease on the second place, PO- on the third, on the fourth – catalase and on the fifth place-urease activity.

On signs of biological efficiency of plants from a projection to discrimination axes (Root 1, Root 2) it can be seen that all test options differed from check ones and also from each other. Though significant differences are found only for option with Secateurs (figure 1b).

In Figure 1b it is shown that check and option with Secateurs differed on an axis of Root 1 and did not differ on Root 2 axis. The relative contribution of each indicator to difference between options of an experiment made up: height of plants> number of cones in an ear> seed efficiency.
At the following investigation phase we analyzed signs of initial variables and drew the following conclusions that to the right on the axis Root 1 there are options with the increased height of plants, increased seed efficiency but with the lowered number of cones in an ear. To the left on the axis there are options with the lowered height of plants, lowered seed efficiency, but with the increased number of cones in an ear. As check on this axis was located at the right, and option with Secateurs - at the left, it is possible to note that treatment by the preparation Secateurs led to decrease in height and seed efficiency of plants, but to increase in number of cones in an ear in comparison with check.

Also on a projection of the dots of the discriminant analysis presented in the drawing it is seen that options with the Puma and tank mixture of preparations differed among themselves generally on Root 2 axis. The main contribution to division was made by seed efficiency and to a lesser extent by height. Up the axis of Root 2 there were located options with the increased seed efficiency and the lowered height of plants. With an axis the seed efficiency positively correlated, and slightly more negatively - height of plants.

For resistance assessment of the "soil-plant" system to the disturbing factors there were calculated the indexes of enzymatic activity (IEA) and biological efficiency (BEI) which are determined by a ratio of indicators values in experiment to indicators in check.

![Figure 2. Indexes of enzymatic activity of the soil (IEA) and biological efficiency of cultural plants (BEI).](image)

Proceeding from the calculated indexes, the herbicide Secateurs have the greatest negative effect, both on the soil, and on plants, which was reflected also in considerable decrease in the calculated indexes. In option with Puma complete recovery of the "soil-plant" system and even its insignificant stimulation was observed that is confirmed by high rates of IEA and the BEI. In test option with tank mixtures of preparations reduction of IEA is noted, however BEI indicators in this option of test were restored to the check level (table 2).

As a nonverbal way of the basic structure description of a system we used a method of the correlation count.

According to this method the relation sign indicates the relations nature between the corresponding elements of a system. Negative relation in ecology is treated as incompatibility of elements; according to the Gauze law, the incompatibility results from competitive exclusion [6]. Existence of positive relation in ecology is treated as compatibility of elements and states the harmonious relations between them. Besides, the method allows to reveal situations when tension in a system sharply increases [7].

As it is seen from figure 3, in general, in the soil as a system there is traced a certain destabilization of processes that affected correlation relations structure. It should be noted that though drawings at first sight are not similar to each other at all, there are similar elements in them. So, the check option and option with Puma are similar in relations structure (2 negative and 1 positive), only enzymes change. In options with Secateurs and P+S the relations orientation changes, and in option with tank mixture of herbicides there are more reliable relations, unlike option with Secateurs.
Figure 3. Correlation relations structure between enzymatic activity indicators of the soil 0-15 cm depending on the test option. Note: K-catalase, Y- urease, P - protease, PO – polyphenol oxidase, Ac – ascorbate oxidase.

In soil samples after use of chemical protection means on crops of wheat, functional relations between the studied parameters, structure of correlation relations, number of blocks, their ratios as well as the sign of relation changed from "+" to "-".

Positive relations availability in the correlation matrix proves that elements compatibility exists in the system and states the harmonic relations between them. In its turn the opposite sign proves the inverse processes in the researched system. It can be supposed that in the subsystem affected by herbicides the elements imbalance occurred.

Thus, in the matrix analysis it is possible to establish that in options after herbicides use there was observed its structure change by means of smaller number of blocks formation, loss of connectivity, sharp change of a ratio of positive and negative relations.

Further we analyzed correlation relations structure of cultural plants (figure 4).

Figure 4. Structure of correlation relations between indicators of biological efficiency of parental plants of wheat of a variety Altayskaya 70 depending on test option.

Note: 1. Plants density, pcs/m²; 2. Plants height, cm.; 3. green weight of top, g.; 4. Weight of 1 plant, g.; 5. generative shoots density pcs/m²; 6. number of cones in an ear, pcs.; 7. Number of grains in 1 ear, pcs.; 8. Number of grains per 1 cone, g.;9. Weight of 1000 grains, g.; 10. Seeds efficiency g/m².

Herbicide Puma and its tank mixture with Secateurs made the smallest impact on plants development as the relations structure and their blocks were brought closer to check. Herbicide Secateurs, apparently, was more toxic in relation to the protected culture what was shown in elements coherence reduction of biological efficiency, their desynchronization and weakening of relations correlation.
The correlation structure of a system allows to reach its integrated characteristics allowing to characterize its state. It is possible to refer rigidity of a system to such indicator. In check there is observed very high rate of rigidity (table 1) which characterizes a system as "rigid", and in the options subject to influence of herbicides Secateurs and P+ S, the rigidity decreases. Perhaps, it is connected with the fact that the subsystem is beaten out from balance. As for plants, in general this parameter was lower here and slightly decreased in test options in comparison with check ones. It can be connected with the fact that plants are more plastic, metabolic processes proceed more intensively in them and thanks to that, they quicker and easier adapt to the changing environment conditions. Some decrease in rigidity in option with Puma is explained by the fact that this preparation fights against monocotyledonous weeds what could impact to greater extent wheat plants as well.

Table 1. Coefficients of rigidity of components of system «soil–plant».

| Test option | Subsystem rigidity | Deviation proportion from the check, % | Deviation proportion from the check, % |
|-------------|-------------------|----------------------------------------|----------------------------------------|
|             | «soil»            | «plant»                                 |                                        |
| Check       | 0,94              | 0,80                                   |                                        |
| Secateur    | 0,70              | -25,5                                  | 0,79                                   |
| Puma        | 0,87              | -7,9                                   | 0,75                                   |
| P+S         | 0,65              | -30,9                                  | 0,78                                   |

In this research there has been made an attempt to define character and the direction of the soil and cultural plants reaction to herbicides impact as a factor external in relation to a system with aid of the system analysis elements. Ecological systems, including agroecosystems, being imbalanced, normally have to adapt to external impacts if they act constantly in one direction, or after cancellation of an external factor action to return to the initial state. In this stability of a system is manifested.

The subsystem of "plant" was in general less rigid and reacted less to the disturbing factor as live organisms possess the genetic program created in the course of evolution, and this program has limited potential of adaptive reactions within one generation. However, on the other hand the same property gives big stability to a subsystem thanks to which it quickly enough returns to an initial state, and in certain cases, after selection, can acquire new properties.

The stress factor influence leading to instability condition in one part of a system is compensated by bigger stability of other part of a system. Therefore, it is possible to consider that the "soil-plant" system is capable to support a homeostasis at influence on it of the studied multicomponent herbicides.

This research makes a certain contribution to development of the agroecosystems management theory in the multicomponent herbicides application conditions, and similar data analysis technique will be useful when developing adaptive systems of agriculture with use of modeling methods.

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