The study of prehistory and chemical properties of soils on their alleloxicity formation

G Fedotov¹, I Gorepekín¹, V Shalaev² and Y Batyrev²

¹Lomonosov Moscow State University, GSP-2, Leninskie Gory 1, p. 12, Moscow 119992, Russian Federation
²Bauman Moscow State Technical University (Mytishchi branch), 1st Institutskaya Street 1, Mytischi 141005, Moscow region, Russian Federation

Abstract. The influence of prehistory (land-use history) and soil chemical properties on their alleloxicity was studied on 12 soil samples of East-European plain with the use of 6 seed cultivars of spring wheat as well as seeds of barley, rye, and triticale. It is shown that despite differs ratio between the values of inhibition for different cultivars, their inhibition order on various soils preserves generally. Land use-history has a significant influence on soil alleloxicity values: soil samples from territories of agricultural use have higher alleloxicity in comparison with fallow areas. The experimental data show that crop rotations are not always able to reduce soil fatigue. This makes it necessary to assess the real soil fatigue (soil alleloxicity) under the crop rotation. The material under consideration, methodological approaches and conclusions can be used in forestry.

1. Introduction

Soil fatigue is a well-known phenomenon in agriculture which leads to a soil fertility decrease. It is observed well under the monocultures cultivation. In works on allelopathy, it is emphasized that the basis of soil fatigue is the accumulation of alleloxicins in soils [1-16]. Sources of these compounds are plants and microorganisms excretions, as well as substances are formed during the decomposition of plant residues. However, alleloxicins accumulation occurs not only in agricultural soils. The study of several thousands of soil samples that was carried out by N.A. Krasilnikov showed that almost all of them had a toxic effect on both higher plants and microorganisms [5].

Despite wide distribution of allelopathic soil toxicosis the study of this phenomenon has remained insufficient. One of reason explained it is the confidence that with further advance in the application of chemicals, soil amelioration, and intense soil treatment, the role of crop rotation would be diminished and the problem of soil toxicosis would cease to exist [7]. Another problem is the study of soil chemical composition does not allow determining the existence of soil toxicosis and its values. So biotesting methods are basic for soil toxicosis studying. In most cases, the study of soil extractions effect on seed development or the assessment of test-cultures set development in certain soils is carried out. This makes it possible to obtain information about soil toxicosis only at a qualitative and semi-quantitative level. However, even results obtained in such way correlate well with soils alleloxicity causing their fertility and yield of agricultural plants [6].
The development of improved method allowed obtaining the quantitative information on soil allelotoxicity makes it possible to wide our views about this phenomenon so it was of interest to study the influence of land-use history and chemical properties of soils on their allelotoxicity.

2. Methods and Materials
The study was carried out with the seeds of spring wheat (Triticum) of Liza, Zlata, Ester, Agata, Lyubava, and RIMA cultivars, winter triticale (Triticeae) of Nemchinovskii 56 cultivar, spring barley (Hordeum) of Nur cultivar, and winter rye (Secale cereale) of Tatiana cultivar.

Samples of the following soils were used in the work: cultivated soddy-podzolic deeply podzolized (1), after mustard (2), after potato (3), and after barley (4); soddy surface- podzolized deeply plowed light loamy soil on glaciofluvial deposits after potatoes from 2015 (5); soddy surface podzolized deeply plowed light loamy soil on mantle loams underlain by moraine, fallow, illuvial horizon (6); soddy-podzolic deeply plowed strongly eroded soil on mantle loams underlain by glaciofluvial deposits after potatoes (7); deeply podzolic weakly differentiated light loamy on mantle loams underlain by glaciofluvial deposits old-arable soil under forest, litter (8); agricultural soddy deeply podzolic sandy loamy soil on glaciofluvial (ancient lacustrine) deposits underlain from the depth of 92 cm by noncalcareous loesslike loams after wheat (9); typical medium-deep loamy chernozem on loesslike loams after potato (10); gray forest cultivated weakly eroded loamy soil on loess-like loams underlain by moraine after potato (11); and chestnut medium-deep light loamy on eluvial and colluvial loams, fallow (12). It was supposed that such a diversity of objects would make it possible to better understand the causes of soil allelotoxicity development.

To assess the soil allelotoxicity it is necessary to choose «starting point» or in other words substrate without toxins. In our case, washed river sand with particles 0.5–0.8 mm was such substrate. Inhibition of seeds development in soils in comparison with sand can be expressed in % with a minus sign, i.e. the more inhibition the more its absolute value.

The influence of soil on the length of seedlings was studied in 7.5 g seed (~200 seeds) germinated in different soils in comparison with sand. The length of seedlings was determined using the express method based on linear relationship between the bulk volume of germinated seeds and the length of their seedlings.

Germinated in soil or sand seeds were washed and placed by portions into the 100-mL measuring flask filled with water and located on vibrating table with vibration frequency 50 Hz. After placing each portion of germinated seeds, which formed an openwork porous structure, into the cylinder, small load of 8 g weight in the form of rubber cork was placed above and caused the compaction of the structure. After the placement of all germinated seeds into the cylinder, the load was placed above, and additional compaction of the structure was made by tapping (30–40) of the cylinder with seeds on the table. These operations allowed forming the relatively homogeneous structure, and the lower boundary of the load allowed determining the bulk volume with the accuracy to 0.5 mL.

When carrying out the experiments, 30 g of soil or sand were placed on the bottom of 95-mm dish, then 7.5 g of seeds were placed in an even layer, and 30 g of soil or sand were placed above. After this, water was added evenly from the measuring pipette. The experiment was carried out in sixfold with subsequent statistical treatment of the results. In order to minimize the error connected with different quality of seeds 1000–1200 seeds were used in one experiment. Hence, the error of experiment did not exceed 7% at 95% confidence probability. Most experiments were carried out at 23–26 °C.

It is well known, that soil moisture is a significant factor affecting the rate of seed germination. It is evident that seed germination and development of seedlings would decelerate under insufficient moisture due to deficiency of water and due to oxygen deficiency under excessive moisture. So, the comparison of substrates with different affinity for moisture (sand and soils) should be correct only in the points, providing optimal water-air conditions and maximal rate of seed development. Optimal
initial quantity of water for substrates was determined by maximal emission of carbon dioxide during seed germination depending on water content in the substrate [8].

Following chemical properties of soil were determined: pH (KCl), contents of exchangeable potassium, mobile phosphorus, exchangeable calcium, and total contents of carbon, nitrogen, and sulfur. Measuring of pH and determination of the contents of potassium (K2O), phosphorus (P2O5), and mobile calcium in the soil were carried out according to commonly adopted methods [17, 18] using photoelectric colorimeter KFK-3 and flame photometer PFM. Soil concentrations of N, S, and C were determined in CHNS-analyzer Vario EL III, Elementar, Germany.

3. Results and Discussion

The results of the study of soil influence on germination of wheat seeds and development of seedlings are presented in table 1. The chart of inhibition of different wheat cultivars by soils under the study were built on the basis of these data (figure 1). It is well seen that cultivars differed in their response to allelotoxins. Some of them demonstrated higher resistance to the complex of allelotoxins in all soils (Liza cultivar), while other cultivars are more intensely inhibited by allelotoxins in all soils (Ester). Other wheat cultivars were found to respond in between. It was seen that the order of inhibition of cultivars by allelotoxins was approximately the same for each soil, though the ratio between the inhibition values for different cultivars could differ.

The data obtained for barley, triticale, rye, and wheat on zonal soils (figure 2), suggested that the regularity of effects of allelotoxins complexes observed for spring wheat were typical for these grain crops either. Such results allow assuming the existence of the same nature of response of the studied grain crops to the complexes of allelotoxins.

Table 1. The inhibition of spring wheat seeds, which is determined by the change in the total seedlings length of the seed array for 2 days in the soils in comparison with sand, %.

| № of soil | Prehistory | The inhibition of spring wheat "Liza" cultivar | The inhibition of spring wheat "Agata" cultivar | The inhibition of spring wheat "Lubava" cultivar | The inhibition of spring wheat "Zlata" cultivar | The inhibition of spring wheat "Rima" cultivar | The inhibition of spring wheat "Ester" cultivar |
|-----------|------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1         | Vetch-oat mixture | -5                                            | -24                                           | -32                                           | -34                                           | -37                                           | -56                                           |
| 2         | Mustard    | -16                                           | -36                                           | -48                                           | -47                                           | -60                                           | -72                                           |
| 3         | Potatoes   | -20                                           | -37                                           | -57                                           | -55                                           | -61                                           | -76                                           |
| 4         | barley     | -21                                           | -34                                           | -53                                           | -51                                           | -61                                           | -80                                           |
| 5         | Fallow     | 23                                            | 0                                             | 16                                            | 0                                             | 5                                             | -7                                            |
| 6         | Fallow     | 0                                             | -19                                           | -1                                            | -17                                           | -5                                            | -19                                           |
| 7         | Potatoes   | 0                                             | -35                                           | -29                                           | -49                                           | -49                                           | -67                                           |
| 8         | Forest litter | 0                                             | -17                                           | 2                                             | -11                                           | 9                                             | 6                                             |
| 9         | Wheat      | -49                                           | -52                                           | -34                                           | -42                                           | -36                                           | -65                                           |
| 10        | Potatoes   | -16                                           | -34                                           | -42                                           | -41                                           | -45                                           | -65                                           |
| 11        | Wheat      | -42                                           | -69                                           | -76                                           | -85                                           | -86                                           | -94                                           |
| 12        | Fallow     | -3                                            | -17                                           | -14                                           | -10                                           | -11                                           | -13                                           |

*Full names of soils are given in the section "Methods and Materials".

It follows from the observed regularity that the cultivar more resistant to allelotoxins of one soil will be also more resistant to allelotoxins of another soil. The presence of order in crops (cultivar) resistance to allelotoxin complex of certain soil can be useful in agriculture when choosing variety for sowing.
It is well seen from the presented data that minimal value of inhibiting among the fields, where the fourcourse rotation was used, was observed in the field 1, where vetch and oat mix were used as a preceding crop. However, wheat was planned to be sown according to the crop rotation after potato on field 3, where the value of inhibiting was much higher for all six cultivars. These data suggest that crop rotation without control of allelotoxicity of fields cannot guarantee positive result in yield increase.

**Figure 1.** Soil influence on seed germination and development of seedlings of different wheat cultivars. Soil numbers and names are presented in the section "Methods and Materials».

**Figure 2.** Influence of soil on seed germination and development of seedlings of wheat cultivar Lyubava, barley cultivar Nur, rye cultivar Tatiana, and triticale cultivar Nemchinovskii 56. Soil numbers and names are presented in the section "Methods and Materials». 
It attract attention that soil alleloxicity is more typical for agricultural lands regardless of the crops being grown. Minimal values of alleloxicity were observed for fallow plots (soil samples 5 and 12) and for litter under forest (soil sample 8). Stimulation, but not inhibiting, by soils of seed germination and seedling development was observed on such soils for the crops most resistant to allelooxins.

The study of various soil horizons alleloxicity (samples 5 and 6) confirmed previously known data that soil alleloxicity increases with depth [2, 6].

Conducted analysis of soil chemical properties show that the availability of nutrients in soils was sufficient for testing and could not limit seed development (table 2). Along with this no correlation between inhibition and studied chemical properties could be found.

Table 2. Chemical properties of studied soils.

| № of soil | Ca, mg/100g | pH (KCl) | N, % | P2O5, mg/100g | K2O, mg/100g | S, % | C, % |
|-----------|-------------|----------|------|----------------|---------------|------|------|
| 1         | 208         | 6.2      | 0.29 | 31.5           | 36.95         | 0.09 | 3.33 |
| 2         | 216         | 6.3      | 0.35 | 32.5           | 25.90         | 0.10 | 3.91 |
| 3         | 167         | 5.9      | 0.23 | 31.5           | 29.80         | 0.07 | 2.57 |
| 4         | 117         | 6.1      | 0.20 | 31.0           | 22.05         | 0.06 | 2.23 |
| 5         | 83          | 5.5      | 0.17 | 14.5           | 6.48          | 0.05 | 1.82 |
| 6         | 67          | 5.1      | 0.04 | 3.0            | 3.25          | 0.02 | 0.26 |
| 7         | 67          | 5.1      | 0.17 | 17.5           | 7.15          | 0.04 | 1.71 |
| 8         | 117         | 3.6      | 1.18 | 6.0            | 11.00         | 0.39 | 35.1 |
| 9         | 133         | 6.6      | 0.14 | 29.0           | 19.45         | 0.05 | 1.65 |
| 10        | 316         | 5.3      | 0.24 | 4.0            | -             | 0.08 | 3.58 |
| 11        | 100         | 5.0      | 0.12 | 18.5           | 15.55         | 0.05 | 1.07 |
| 12        | 150         | 6.2      | 0.09 | 5.5            | 11.00         | 0.05 | 0.80 |

*Full names of soils are given in the section "Methods and Materials".

4. Summary

In conclusion, it is possible to draw certain conclusions:
- different cultivars of spring wheat are inhibited by soils according to revealed regularity. Despite differ ratio between the values of inhibition for different crops, their inhibition order on various soils preserves generally;
- territories of agricultural use were characterized with a greater alleloxicity compared with fallow and forest areas;
- the experimental data show that crop rotations are not always able to reduce soil fatigue. This makes it necessary to assess the real soil fatigue (soil alleloxicity) under the crop rotation;
- the material under consideration, methodological approaches and conclusions can be used in forestry.

Acknowledgments

The work was supported by Ministry of science and higher education of Russian Federation.

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