Research Article

Influence of Copper Pollution of Haplic Calcic Chernozem With Various Contents of Sand Fractions on Morphobiometric Indicators of Spring Barley

Saglara Mandzhieva[1]*, Natalia Chernikova[1], Tamara Dudnikova[1], David Pinskii[2], Tatiana Bauer[1], Inna Zamulina[1], Anatolii Barahov[1], Marina Burachevskaya[1], Tatiana Minkina[1]

[1]Southern Federal University, Rostov-on-Don, Russia
[2]Institute of Physicochemical and Biological Problems of the Russian Academy of Sciences, Pushchino, Russia

ORCID ID:
Saglara Mandzhieva 0000-0001-6000-2209
David Pinskii 0000-0002-5834-5648
Tatiana Bauer 0000-0002-6751-8686
Marina Burachevskaya 0000-0002-0533-0418
Tatiana Minkina 0000-0003-3022-0883

Corresponding Author: Saglara Mandzhieva; email: msaglara@mail.ru

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Abstract. The growth and development of plants is one of the criteria for assessing the degree of soil pollution with heavy metals. Morphological and anatomical changes in test plants affected by pollutants, such as growth retardation, shoot bending, and decreased root length and mass, indicate the worsening of environmental conditions. The effect of various ratios of soil and sand polluted with copper (Cu) on morphobiometric parameters of spring barley (*Hordeum sativum distichum*), Ratnik variety, was studied in a model vegetative experiment. Haplic calcic chernozem was used as a substrate with different ratios of soil/sand. It was determined that an addition of sand into the soil in the amounts of 25%, 50% and 75% of soil mass resulted in the alteration of the physical properties of the chernozem, which was reflected in the morphometric parameters of the plants. The most notable changes in the parameters were observed after pollution of soil-sand substrates with $Cu(CH_3COO)_2$ in the amounts of 250 mg/kg, 500 mg/kg, 1000 mg/kg and 2000 mg/kg. The maximum growth and development retardation of the barley plants was found at the maximum content of sand and the maximum concentration of Cu. The pollutant reduced the root length and, to a lesser degree, the height of the aboveground components of the plant, which as a result, decreased the total plant biomass.

Keywords: trace elements, soil, agricultural crops, particle size distribution

1. Introduction

Anthropogenic impact on the environment results in disruption of natural biogeochemical cycles of substances, accumulation of toxicants in trophic chains, the final link of which is a man. Moreover, the greater part of the anthropogenic emissions in various forms accumulate in soil, making it toxic for living organisms, and large amounts of pollutants change its chemical and biological properties, which leads to an increase in phytotoxicity [1].

In this case, the plants are the most vulnerable component of the biota, since they are the primary links of natural food chains and play the main role in the absorption of various pollutants from soil [2]. One of the criteria for assessment of the level of soil contamination with heavy metals is their effect on the growth and development of plants. Morphological and anatomical changes in test plants affected by pollutants such as growth retardation, bending of shoots, a decrease in the length and mass of roots indicate the worsening of environmental conditions. Thus, the variability of the morphometric parameters of plants, first of all, is most relevant for diagnostics of the content of metals in soil [3]. Changes of the height of plants, their productivity, bushiness or quality of grain (fruits) are possible when metal permeate through physiological barriers with an increase of its concentration in soil [4, 5, 6, 7]. It is known that an increase of the concentration of metal in soil enhances the negative effect of heavy metals on growth processes, the development of stem meristems and roots [4, 8, 9, 10].

Analysis of literature data shows that a low level of soil pollution with heavy metals does not have a clear negative effect on plants, which is explained by the triggering of physiological defense mechanisms of the plant organism [4, 9]. A significant increase in metal doses (up to 1000 mg/kg and above) in soil results in drastically negative changes of almost all plant parameters including seed germination and finally, the crop yield indicators, in some cases, the death of plants [4, 9, 11, 12].

Copper, as a chemical element, is widely distributed in plant tissues and is an important trace element for their growth. However, copper becomes toxic when its content exceeds a threshold level, which depends on the plant species. Copper has a high technophilicity and is used in various industries, which leads to an increase in its production and the associated inevitable soil pollution with this metal. The purpose of this work is to analyze the morphobiometric parameters of spring barley grown on substrates with different ratios of soil and sand contaminated with copper.

2. Materials and methods

Haplic Calcic Chernozem (20-cm layer) was used as a substrate with various ratios of soil and sand was in the model vegetative experiment. Haplic Calcic Chernozem (average humic heavy loamy chernozem on loess-like loamy soils) was collected in strictly protected nature territory Persianovskaya Steppe (Table 1) located away from possible pollution sources. Physical-chemical properties of soils were determined according

TABLE 1: Physical and chemical properties of Haplic Calcic Chernozem

Humus, %	pH water	$N\text{-}NO_3$,	P_2O_5, subsp.,	K_20, ex.,	Exchangeable bases		$CaCO_3$, %	Physical clay, %	Silt, %
					Ca^{2+}	Mg^{2+}			
		mg/100 g			meq/100 g				
3.9±0.2	7.6±0.1	1.0±0.1	6.1±0.3	36.7±1.4	31±1.8	3.5±0.2	0.25±0.01	59.0±2.3	33.5±1.1

to GOSTs: pH of water extract according to GOST 26423-85; total humus content (C_{org}) according to GOST 26213-91; exchange capacity of cations and exchangeable cations Ca^{2+} and Mg^{2+} by Shaimukhametov's method [13]; the content of carbonates by acidimetry. Granulometric composition (GMC) soil was determined by pipette method with pyrophosphate sample preparation [14].

The experimental scheme consisted of 18 variants in 3 replications and included variants with soil dilution with washed quartz sand in concentrations of 25, 50 and 75% of the soil mass. The $Cu(CH_3COO)_2$ was added into soil (with and without sand) in concentrations 250, 500, 1000 and 2000 mg/kg. After a month, the seeds of the spring barley (*Hordeum sativum distichum*) Ratnik variety were seeded by 15 seeds per vegetative vessel (Figure 1). Germination and energy capacity of seeds were preliminary determined according to GOST 12038-84 and GOST 10968-88. The used spring barley species characterized with high germination activity. Soil moisture corresponded to lowest field water capacity was maintained over all experimental period. The experiment was performed at the natural illumination in greenhouse complex of the Botanical Garden of the Southern Federal University (placeCityRostov-on-Don, country-regionRussia).

In 40 day after germination, the plants with roots (GOST 27262-87) were collected for further analysis. The soil samples were collected together with the plants. Germination rate and germination energy of seeds along the analysis of morphobiometric parameters of the spring barley plants (height of plants, root length, total biomass) have been studied for all variants of the experiment.

3. Results and discussion

It is shown that the addition of sand in an amount of 25, 50 and 75% of the soil mass changes the growth and development of barley plants in a model experiment with uncontaminated Haplic Calcic Chernozem (Table 2). Insufficient increase of root length and plant height occurs at a soil-sand ratio 4 : 1. The subsequent increase of the amount of sand in soil negatively affected these parameters.

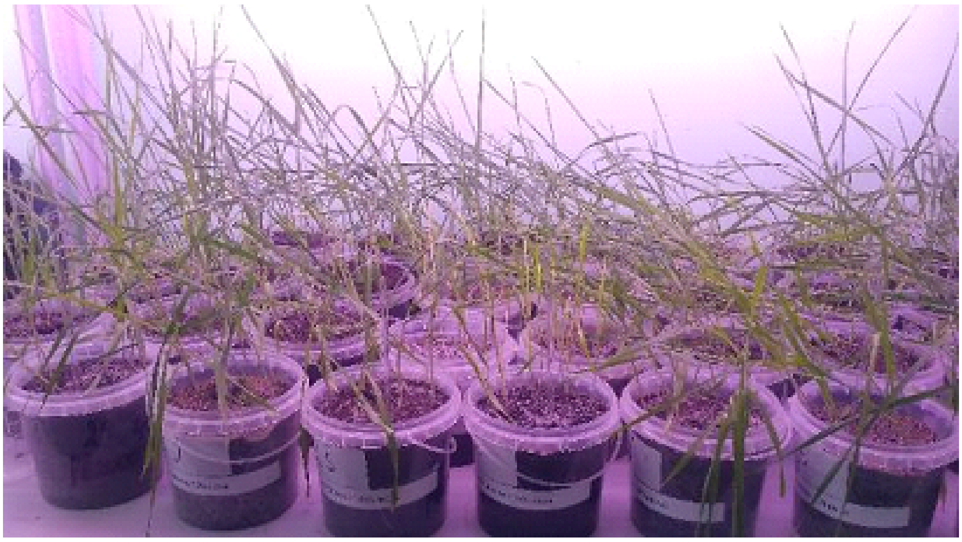

Figure 1: Model vegetative experiment.

Significant changes in the studied parameters of plants are observed after contamination of soil-sandy substrates with Cu (Table 2). The introduction of Cu in amounts 250, 500, 1000 and 2000 mg/kg inhibits the growth of plant roots. The toxic effect of metal on a plant can be traced by the growth of the root system, which is the first barrier for the entering of toxicants, as well as shoots [15]. The toxic effect increased with an increase of the dose of Cu and the amount of sand in the substrate.

The height of cereal plants reflects the general condition of plants in the growth phase and formation of biomass and reveals their response to nutritional conditions and soil toxicity [16]. The maximum suppression of root length, height, and dry biomass of plants was found after addition of 2000 mg/kg Cu. The addition of sand to the content of 2000 mg/kg Cu in an amount of 25, 50 and 75% of the soil mass increases the inhibition of root length by 65, 79 and 86 %, plant height by 34, 54 and 68 %, and dry plant biomass by 20, 45 and 69 %.

The germination rate and germination energy of spring barley in variants with uncontaminated soil with different soil-sand ratio did not change. Plant germination was high, and the germination energy decreased after the addition of Cu at a dose of 250 mg/kg with an increasing amount of sand from the total amount of the substrate. The higher content of the pollutant in soil reduces these parameters, while the toxic effect of heavy metal increases with a change in the soil/sand ratio.

TABLE 2: Morphobiometric characteristics and seed quality of spring barley in Haplic Calcic Chernozem after addition of various doses of cooper and sand.

Experimental variants	Root length, cm	Height of vegetative part, cm	Dry biomass, g	Germination rate, %	Germination energy, %
Control	40.4 ± 1.4	49.2 ± 1.6	2.18 ± 0.12	100	100
Control + 25% sand	46.7 ± 1.6	52.1 ± 1.9	2.22 ±0.24	100	99
Control + 50% sand	35.2 ± 2.0	43.9 ± 1.8	2.07 ± 0.39	99	98
Control + 75% sand	31.9 ± 1.9	37.4 ± 2.0	2.0 ± 0.34	100	99
Cu 250	35.1 ± 1.7	44.5 ± 2.0	1.8 ± 0.33	98	94
Cu 250 mg/kg + 25 % sand	29.6 ± 2.2	42.1 ± 2.3	1.75 ± 0.32	98	94
Cu 250 mg/kg + 50 % sand	25.9 ± 1.5	37.4 ± 2.2	1.33 ± 0.41	96	92
Cu 250 mg/kg + 75 % sand	24 ± 2.1	32.2 ± 2.6	1.19 ± 0.17	93	89
Cu 500	28.2 ± 1.9	43.8 ± 3.6	1.42 ± 0.47	79	75
Cu 500 mg/kg + 25 % sand	22.5 ± 2.3	40.6 ± 2.8	1.25 ± 0.18	79	67
Cu 500 mg/kg + 50 % sand	18.3 ± 2.6	31.9 ± 2.5	0.97 ± 0.22	74	71
Cu 500 mg/kg + 75 % sand	10.1 ± 2.0	25.6 ± 2.9	0.84 ± 0.19	67	60
Cu 1000	20.8 ± 1.7	36.8 ± 2.5	1.31 ± 0.43	56	53
Cu 1000 mg/kg + 25 % sand	16.8 ± 1.9	29.7 ± 2.0	1.07 ± 0.30	53	45
Cu 1000 mg/kg + 50 % sand	13.1 ± 2.1	19.3 ± 3.3	0.81 ± 0.32	53	42
Cu 1000 mg/kg + 75 % sand	9.5 ± 2.7	18.6 ± 4.1	0.79 ± 0.26	42	37
Cu 2000	12.1 ± 1.8	25.2 ± 2.7	1.0 ± 0.15	32	22
Cu 2000 mg/kg + 25 % sand	4.2 ±2.5	16.6 ± 2.0	0.80 ± 0.20	25	20
Cu 2000 mg/kg + 50 % sand	2.5 ± 2.6	11.5 ± 2.6	0.55 ± 0.23	25	16
Cu 2000 mg/kg + 75 % sand	1.7 ± 2.0	8.2 ± 2.7	0.31 ± 0.19	15	8

4. Conclusions

Addition of sand into soil changes the physical properties of soil, which are reflected in the changes of morphometric parameters of plants in conditions of cooper pollution. Introduction of pollutant reduces the root length and in lesser degree the height of vegetative part that reduces the total biomass of the plats. The addition of sand to soil

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in the amount of 25, 50, and 75 % of the substrate mass results in the greater reduction of plant growth in soils polluted with cooper.

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