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Photosynthetic Activity of Plants and Dynamics of Growth Process in Soil Contaminated by Cadmium

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Abstract

The article presents the results of field studies on the effect of different doses of cadmium on the assimilating leaf area, photosynthetic potential, its change as the area of the leaf surface formed in a particular interfacial period, and the duration of the interfacial period. The introduction of cadmium in a dose of 10 mg/kg of soil had a negative impact on the increase in the vegetation phases and on the accumulation of the total potato biomass by the end of the vegetation. At the same time, the output of the obtained products per 1000 units of photosynthetic potential decreased by 0.24 kg of tubers compared to the background version. On average, for 2 years of research, the maximum value of leaf productivity was observed at a dose of cadmium 1 mg/kg, which is most likely due not to the biological need for it, but to stimulating intoxication.

Keywords: heavy metals, cadmium, photosynthetic potential, net photosynthetic productivity, leaf productivity.

1. INTRODUCTION

Heavy metals are one of the priority pollutants of air, soil and water bodies on a global and regional scale, which is largely due to their biological activity [9,14]. They are stable in the environment, can accumulate in the tissues of living organisms and be transmitted through food chains [11].

Getting in different ways in the atmosphere and soil, TM come first in plants, and then – in the human body and animals.

It is believed that from 60 to 90% of all trace elements humans and animals receive from plant food, so it is no exaggeration to talk about the chemical composition of plant products as a factor determining the health of mankind as a whole [6, 7].

It should be noted that the plants themselves absorb heavy metals selectively, having a certain protective system in relation to the toxicants. At the same time, there is an uneven distribution of chemical elements in plant organs [15,17].

Among TM, one of the most mobile elements is Cd, some of which enters the cell cytoplasm and can have multiple toxic effects on the metabolism of both producers and consulates [8,9]. In areas of high content of cadmium in the soil is set 20-30 times the increase in its concentration in the ground parts of plants compared with plants unpolluted areas. It is not among the elements necessary for plants but is effectively absorbed by them. Cadmium is mainly localized in the roots and in smaller quantities - in the stems, petioles and main veins of the leaves. At the same time, when the amount of cadmium in the medium rises sharply, the concentration of the element in the roots is several times higher than its concentration in the above-ground mass. It was found that chlorophyll can concentrate cadmium in plant tissues [2,3,13]. Visible symptoms caused by increased cadmium content in plants are chlorosis of leaves, red brown colour of their edges and veins, as well as growth retardation and damage to the root system. Cadmium phytotoxicity is also manifested in inhibitory effect on photosynthesis, violation of carbon dioxide transpiration and fixation, as well as changes in cell membrane permeability [12,17].

Contaminated plants may contain up to 400mg/kg Cd or more. In contrast to other mineral elements (except Zn), Cd can accumulate in relatively large amounts in generative organs. The high phytotoxicity of Cd is explained by its proximity in chemical properties to Zn. Therefore, the Cd can play the role of Zn in many biochemical processes, interfering with the operation of vital enzymes such as carbonic anhydrase, various dehydrogenases, phosphatases and proteases and peptidases involved in protein metabolism, enzymes of nucleic acid metabolism, and others. As a chemical analogue of zinc, cadmium can replace it in an enzymatic system, required to fosforilirovanija of glucose and the accompanying process of formation and breakdown of carbohydrates [16,19].

Due to the increasing flow of heavy metals (HM) into the soil, it became necessary to normalize their content, that is, to establish limits beyond which pollution is unacceptable. A special role is given to the study of the accumulation of pollutants in agricultural plants. It is an important link of ecological and biogeochemical studies related to the study of the evolutionarily formed potential of resistance of plant organisms to various doses of heavy metals; the influence of the latter on the productivity of phylogeneses, activation of the photosynthetic apparatus, the identification of agricultural plants with high resistance to environmental stress [4,8].

The purpose of our research was to study the effect of different levels of soil contamination with cadmium on the performance of the sheet metal and the productivity of *Solanum tuberosum.*

2. METHODS

The research methodology is based on the concept of critical loads, considered as biogeochemical standards for assessing the permissible anthropogenic impact on ecosystems of different levels. In particular, the selection of environmental criteria (critical Cd concentrations) is based on the consideration of the relationship between the chemical parameters of the element characterizing the soil and the response of plants to these parameters.

Studies were conducted in 2017-2018 on the lands of the former farm RGAZU with plants *Solanum tuberosum,* Nevsky variety. The soil of the experimental site is sod-podzolic light-loamy, characterized by low humus content, weakly acidic reaction of the medium, high phosphorus content and high potassium.

The scheme of the experiment presented in the following tables included a background version with ammonium nitrate, double superphosphate and potassium chloride at the rate of 9g N and P_2O_5 and 13.5 g K_2O per 1 m^2. The initial gross Cd content in the soil, determined after boiling in the extract 5 n. HNO_3 and $HClO_4$ (3:1), was respectively 0.40 mg/kg with the proportion of potentially available forms defined in the extract 1 n. HNO_3, 60-70 %. Artificial pollution of Cd was created by introducing Cd $(CH_3COO)_2$ $2H_2O$ into the soil at the rate of 1, 2, 5, 10 mg/kg of soil, respectively, which corresponds to 1 – 10 maximum permissible concentration for these soils. Repeat experiments 4 times. The arrangement of plots was carried out by the method of randomized repetitions.

Plant samples for analysis were taken 3 weeks after germination, during budding, at the end of flowering, 2 weeks after flowering and before harvesting.

The dynamics of dry biomass growth was determined by drying plant samples at a temperature of 105 ° C to a constant weight; the dynamics of sheet surface area growth – by cutting; calculation of sheet photosynthetic potential by the method of A. A. Nichiporovich, etc.; determination of the net productivity of photosynthesis according to the formula proposed by Kidd, West and Briggs [quoted by 10].

3. RESULTS AND DISCUSSION.

A necessary condition for obtaining high yields of plants is the formation of the optimum leaf area Kayumov M. K. (1982) pointed out that in obtaining the yield of potatoes from 15,0 to 30,0 ton\ hectare (t/ha) average area of the leaves can vary from 17 to 34 thousand m^2/ha. the Maximum area it can reach 25-54 m^2/ha; ratio is the ratio between the maximum and the average area of leaves with a yield of 24.0 – 27.5 t/ha is 1.5 to 1.6; photosynthetic potential under such yield is equal to 3025 – 3440 thousand m2/ha x days. These indicators are the basis of crop programming management [10].

One of the main factors regulating the photometric parameters of potato planting is the optimal ratio of different nutrients in the soil. Their imbalance, excessive accumulation of xenobiotic elements can have a negative effect on these parameters.

The results of our studies in table 1 show that 3 weeks after germination, 38-47% of the maximum leaf area was formed in potatoes of the Nevsky variety.

Table 1 - Leaf area and yield of potato when soil is polluted with Cd, the average rate for the 2017 - 2018.

Experience options	Leaf area, thousand m2 per 1 ha					Yield, t/ha
	Sprouting	Budding	Blooming	Period of the greatest tuber - formation	Harvesting	
N+ P+ K (background value)	19,9	32,5	42,4	37,5	26,0	20,9
Background value + Cd 1	18,8	32,5	44,8	40,2	28,6	23,6
Background value + Cd 2	17,9	31,9	43,8	39,0	26,1	22,6
Background value + Cd 5	16,1	30,5	40,8	33,8	25,9	19,9
Background value + Cd 10	15,8	27,9	41,1	31,5	23,7	17,9

The increase in the level of soil contamination with cadmium to 10 mg/kg was accompanied by a decrease in leaf area by 10% compared to unpolluted soil by the beginning of budding. By the flowering period Cd stimulated the formation of the leaf surface. The largest leaf surface in all variants developed by the third decade of July. It reached 44.8 thousand m^2/ha.

By the period of harvesting, regardless of the level of pollution, the leaf area did not differ and amounted to 23.7 – 28.6 thousand m^2/ha. it Should be noted that the rate of increase in the leaf area under the influence of Cd decreased by the beginning of budding by 13 – 20 %. The area of the assimilation surface was within the optimal range for the Nevsky variety and varied over the years of research, reaching a maximum in 2018. Patterns of changes in its values are like changes in the weight of the tops.

Numerous data indicate that the yield of biomass is directly related to the leaf area. However, the large size of the leaf area is still insufficient to ensure that the leaf surface is formed quickly and as long as possible to actively function, this requires a high photosynthetic potential.

Photosynthetic potential (FP), referred to as the "power" of the leaf apparatus, characterizes the possibility of using for photosynthesis of solar radiation crops of agricultural plants during the growing season and is expressed by the integral area of the leaf surface of plants (m^2/ha) in the continuation of the period of active leaf work. It combines two indicators: the area of leaves and the time of their work. FP is a generalizing indicator characterizing the effectiveness of all methods of technology of cultivation of agricultural plants.

Analysis of the results of the studies shown in table 2 shows that in the studies the AF varied from 165-209 thousand m^2/ha x days in the germination phase to 2251 – 2658 by the harvesting period. In this case, the negative effect of cadmium at all levels manifested from the germination phase to flowering. Thus, at the maximum dose of cadmium, the value of AF by the period of budding decreased by 17%.

The effect of TM on the biosynthesis of organic matter and the formation of economically useful features of plants can be due to their influence on the primary assimilation of carbon dioxide, the qualitative direction of photosynthesis, post photosynthetic reactions, transport of plastic substances and their distribution between organs and tissues. As our studies have shown, soil contamination of TM influenced the intensity of accumulation of dry mass of tops and tubers (table. 3).

Potatoes in the first 1.5 months of its development in tubers accumulated 16-21% in the tops of 50-55% of the total dry weight. The rate of growth of dry mass to the flowering phase increased significantly: dry mass of tubers by the end of this period reached 41-60 % of the maximum amount, and the weight of the tops 100%. For 2 months of vegetation potatoes accumulated 71 - 85% of dry weight of the total crop. By the period of the greatest tuber formation, the weight of the tops decreased by 1 17 %, and the tubers increased by 15-35 % (table.3).

Table 2 - Photosynthetic potential of potatoes during fertilization and soil contamination with heavy metals, thousand m2/ha x days (for interphase periods, average for 2017 – 2018)

Experience options	Sprouting (21 days)	Budding (10 days)	Blooming (14 days)	Period of the greatest tuber – formation (22 days)	Harvesting (20 days)	Total
1.N+ P+ K (background value)	209	262	524	918	635	2548
2. Background value + Cd 1	197	256	541	977	687	2658
3. Background value + Cd 2	188	249	530	951	651	2569
4. Background value + Cd 5	169	233	499	857	596	2354
5. Background value + Cd 10	165	218	483	834	551	2251

Under the influence of cadmium to the flowering phase, the rate of dry mass accumulation by tubers decreased by 13-14%. At the same time, even though the dry weight of the tops to the flowering phase reached a maximum, its absolute weight in variants with doses of Cd – 5 and 10 mg/kg of soil decreased by 11-19%. As is known, the share of organic compounds produced during photosynthesis, accounts for about 95% of the total biomass of the plant organism. Therefore, the change in dry weight can fairly objectively reflect the assimilation activity of plants.

This indicator is the basis for the method of determining the "net assimilation" or net productivity of photosynthesis (NPF). Net productivity of photosynthesis is an increase in the dry mass of plants in grams over a certain time (day), referred to a unit of leaf surface (m^2).

Table 3 - Dynamics of dry mass of plants under soil contamination with heavy metals, t/ha average for 2017-2018

Experience options	Sprouting	Budding		Blooming		Period of the greatest tuber – formation		Harvesting	
	Tuber	Tuber	Tops	Tuber	Tops	Tuber	Tops	Tuber	Tops
1.	1,36	1,82	1,03	3,63	3,01	3,01	4,24	2,83	5,01
2.	1,67	2,20	1,13	4,01	2,71	3,97	4,79	3,04	6,29
3.	1,56	2,02	1,06	3,81	2,47	3,77	4,50	2,88	5,89
4.	1,33	1,69	0,85	3,25	2,10	3,16	3,81	2,54	5,01
5.	1,23	1,59	0,74	3,05	1,88	2,99	3,50	2,37	4,60

The definition of "net assimilation" is of interest in the study of photosynthesis in natural conditions. In case of soil pollution TM NPF provides valuable material for finding the most rational ways to improve crop productivity, forecasting and programming of crops, appropriate placement of agricultural plants in conditions of anthropogenic load on the soil.

Table 4 - Net productivity of potato photosynthesis in soil contamination CD, g/m^2 per day.

Experience options	Sprouting	Budding	Blooming	Period of the greatest tuber – formation	Harvesting	Average per vegetation
1.	3,25	5,66	7,22	0,69	0,93	3,55
2.	4,73	6,47	6,27	2,18	0,83	4,10
3.	4,15	6,10	6,04	2,18	0,77	3,84
4.	3,53	5,19	5,63	1,97	0,97	3,46
5.	3,71	5,03	5,38	1,95	0,87	3,39

Indicators of NPF of potatoes were 3 weeks after emergence 3.3 – 4.7; before budding 5.0-6.5; during flowering 5.4 – 7.2; mass formation of tubers 0.7-2.18 and during harvesting 0.8-1.0 g/m^2 per day (table.4). Thus, the value of net productivity of photosynthesis of potato plantings reached the maximum size during budding – flowering. As plants develop, the leaves of the upper tier shade the leaves of the lower tiers, and this leads to an overall decrease in the productivity of photosynthesis.

Cadmium at doses of 1 and 2 mg/kg of soil intensified leaf activity before budding. In the flowering phase, cadmium reduced NPF compared to the background version by 13 -25%). The productivity of 1 thousand units of sheet photosynthetic potential in the background was close to 8 kg of tubers (table.5). Cd soil contamination had little impact on the productive work of the leaves.

Table 5 - Photometric parameters of potato plantings, average for 2 years

Experience options	Yield biol., c/ha (center per hectare)	Leaf area average, thousand m^2/ha	Leaf area max.., thousand m^2/ha	Photosynthetic potential, million m^2/ha per day	Net productivity photosynthesis (NPF), g/m^2 per day	Productivity of leaves (PRL), kg of tubers per 1 thousand units
1.	7,84	31,7	42,4	2,55	3,55	8,2
2.	9,33	33,0	44,8	2,66	4,10	8,87
3.	8,77	31,7	43,8	2,57	3,84	8,79
4.	7,55	29,4	40,8	2,35	3,46	8,47
5.	6,97	28,0	41,1	2,25	3,39	7,96

The literature data describing the growth rates due to the resistance of crops to HM are ambiguous. One view is that the development of resistance to metals requires additional energy costs, and sustainable plants have lower (20-3O%) productivity than unsustainable plants. At the same time, there are studies proving an increase in growth processes in stable forms compared to unstable ones.

Most of the literature data indicate a decrease in the productivity of agricultural plants under the influence of high concentrations of HM. However, there are studies showing that the phytotoxicity of HM is largely determined by the biological belonging of plants to certain groups. The observed positive phenomena in the study of the authors are explained, most likely, not by the biological necessity of heavy metals, but by the stimulating intoxication of the body under the action of micro doses of toxic substances. In any case, it is necessary to select plants that are most resistant to high concentrations of cadmium in the soil and take measures to reduce its mobility [1,5,18].

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