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Features of photosynthetic activity of sowings of corn for grain in conditions of pollution with lead, cadmium, and zinc

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The purpose. To study features of formation of the assimilatory apparatus of plants of corn for grain with growing the crop on edaphic backgrounds, polluted with lead, cadmium, and zinc. **Methods.** Probes were carried out in long small-plot experiment in 1999 in pilot farm “Chabany” NSC «Institute of agriculture of NAAS». The area of leaf surface, photosynthetic potential of sowing (PPS), amount of dry matter, net productivity of photosynthesis (NPP), parameters of fluorescence of chlorophyll pigment were determined in master phases of propagation and growth of plants of corn. **Results.** It is proved that at accumulation of heavy metals in upper 0 – 20 cm layer of grey forest soil processes of formation of the assimilatory apparatus of plants of corn were infringed. PPS had decreased for 7,5 – 34,2%, NPP — for 3,22 – 22,6%. Calvin’s efficiency, determine on parameters of Kautsky curved line, had correlative dependence with PPS of sowing r=0,588 – 0,923 and with NPP — r=0,581 – 0,914. Productivity of mealies had decreased for 6 – 22% in comparison with the supervisory control. **Conclusions.** The close positive correlation between quality and quantity indicators of state of the assimilatory apparatus of plants of corn and productivity of crop (r=0,978 – 0,995.) is revealed.

Key words: *corn, heavy metals, photosynthesis, surface area of a leaf, productivity of photosynthesis, photosynthetic potential, dry matter.*

The realization of the potential of varieties or hybrids of crops is the result of photosynthesis, during which simple substances form energy-intensive and diverse in chemical composition organic compounds [10]. The intensity of accumulation of organic substances depends on the capacity of the assimilation apparatus, which is determined by the biometric parameters of plants and the effectiveness of the activity of chloroplasts, and also depends to a large extent on abiotic conditions, including heavy metals (HM) in the soil [8]. The power of the assimilation apparatus and the duration of its operation are the decisive factors for the productivity of photosynthesis, which causes quantitative and qualitative indices of the crop. Research scientists demonstrated a close relationship processes by the functioning of the photosynthetic apparatus and the physiological state of the plant, depending on abiotic factors [4]. At the same time, there is insufficient information in the scientific literature about changes in the formation of a photosynthetic apparatus and its productivity in the phases of development of crops in conditions of polycomponent soil contamination with heavy metals.

The purpose of the work was to determine the peculiarities of the formation of the assimilation apparatus of corn plants for grain when cultivating the crop on soil background contaminated with lead, cadmium, and zinc.

Methods of research. The studies were carried out in the long dribnodilyakovyh experience "The influence of zinc, lead, cadmium on the productivity of agricultural crops and ecotoxicological characteristics of gray forest soil", laid down in 1999 in the experimental farm "Chabany" of the National Scientific Center "Institute of Agriculture of NAAS" (Right-Bank Forest-Steppe, Kyiv region). The soil is gray forestless Cambrian. In the experiment variants with artificially created lead, cadmium, zinc backgrounds are provided: 1 – natural background of zinc, lead and cadmium (control); 2 – excess of the natural background of metals

10 times, 3 – 100 times; The fourth 5 times. The object of research was permanent during 2012–2014. Agrocenosis of corn (hybrid Zdvizh MV). The sowing was carried out in a wide-grain way, the fertilizers were applied in all areas in spring in the presowing treatment at a dose of $N_{120}P_{90}K_{120}$. The repetition of the experiment is fourfold.

With the main phases of growth and development of corn plants, the area of the leaf surface, the photosynthetic seeding potential (PSP) [8], the amount of dry matter, the net productivity of photosynthesis (NPS) [6] were determined.

To study the functional characteristics of the photosynthetic apparatus of corn plants, the chlorophyll fluorescence induction (CFI) method was used. The fluorescence parameters of chlorophyll were determined in the field (in vivo) using a portable fluorometer "Floratest", without violating the integrity of the studied plants. The induction of chlorophyll fluorescence naturally changes with the age of the leaf of the plant, therefore, to assess the effect of heavy metals on the state of the photosynthetic apparatus of corn, measurements were made separately in the 3–4-leaf phase, ejection of panicle, milk ripeness. To obtain physiologically significant results, the main kinetic parameters were determined: Fo – background fluorescence, Fm – maximum fluorescence yield, Fst – stationary fluorescence. On the basis of which the coefficient of the maximum efficiency of the primary processes of photosynthesis was calculated (Fv/Fm) and the efficiency of the Calvin – ((Fm-Fst)/Fst cycle).

Statistical processing of data was carried out using standard computer programs Microsoft Office Excel 2003 and Statistica.

Results of the research. It was found that when growing corn on soils contaminated with HM, the area of the leaf surface decreases in plants (Tabl. 1). Varying the indicator, depending on the variants of pollution and development phases, varied from average to significant (V = 16,8–24,7 %). With an increase in the concentration of HM in the soil medium, the intensity of the growth of the leaf surface decreased. Thus, in the phase of maximum development of the photosynthetic apparatus, the panicle ejection, the growth of the leaf surface in corn plants, by a 5-fold increase in the amount of HM in the soil, decreased by 7,1 %, for 10-fold – 25,0 %, 100-fold for 33,1 % compared to the control.

In the period of active vegetation of plants (from the beginning of the generative period to the filling of grain, milk ripeness), the optimal leaf area is 40-60 thousand m^2/ha. This area is reached by plants in the phase of throwing panicles and flowering beyond the natural background of the HM. In agroecotopes with a fivefold and tenfold increase in the natural background of the HM only in the flowering phase, the area of the leaf surface reached 44,1–48,5 thousand m^2/ha, and a 100-fold excess of the optimal level was not achieved.

An important indicator of the state of the assimilative apparatus of crops is the photosynthetic potential of inoculation (PSP). It is he who determines the productivity of sowing, since it is closely related to the area of the leaf surface of plants and the duration of the functioning of the photosynthetic apparatus. In our studies, the correlation coefficient between the area of the leaf surface synthesized by plants in the main phases of their growth and development, and the PSP was within the range of 0,961 to 0,999.

1. The area of the leaf surface of corn and PSP, depending on the content of HM in the soil, thousand m^2/ha (average for 2012–2014)

Option of experience (pollution degree)	Phases of growth and development					PSP, mln. m^2·days/ha
	3-4 leaves	10–12 leaves	Throwing out the whisk	Flowering	Milk ripeness	
1– natural background of HM (control)	0,83	9,31	40,1	52,1	37,3	2,81
4– five times the natural background of the HM	0,71	9,01	37,6	48,5	32,6	2,60
2 – a tenfold excess of the	0,61	8,56	31,7	44,1	29,7	2,32

natural background of the HM						
3 – hundredfold excess natural background HM	0,45	6,25	26,8	34,8	22,4	1,85
$\bar{X} \pm S\bar{x}$	*0,65± 0,08*	*8,28± 0,69*	*34,1± 3,0*	*4,8± 83,7*	*30,5± 3,1*	*2,40± 0,21*
V,%	*24,7*	*16,8*	*17,6*	*16,6*	*20,5*	*17,3*
S	*0,16*	*1,39*	*5,9*	*7,5*	*6,2*	*0,42*

The variability of the PSP within the experiment did not exceed the average (V = 17,3 %), and the absolute value varied from 1,85 to 281 million m^2 days/ha. According to A. A. Nichiporovichem crops are considered good if the PSP is within the range of 2,2–3,0 million m^2 days/ha. These included only the crops formed in the control areas and five to ten times the HM background. The worst in the experiment was the state of crops with the maximum content of HM in the soil (option 3).

An important indicator characterizing the productivity of photosynthesis is the accumulation of dry matter by sowing agricultural crops. For the conditions of Ukraine, this indicator is considered good at 7,0-8,0 t/ha, high – 10,0-12,0, very high – 14,0-16,0 t/ha dry matter.

The amount of dry matter accumulated by corn plants during the vegetation period changed in accordance with the area of the leaf surface (Fig. 1). The correlation coefficient between these indicators was 0,889-0,989, and the variability of the accumulation of dry matter in the variants of the experiment according to the phases of plant growth and development was medium and significant (V = 15,9–38,9 %). The least amount of dry matter was synthesized by plants of the variant with a hundredfold excess of the background. Here, in the phase of milk ripeness, 10,3 t/ha of dry matter was achieved, which is 34 % lower than in the natural background.

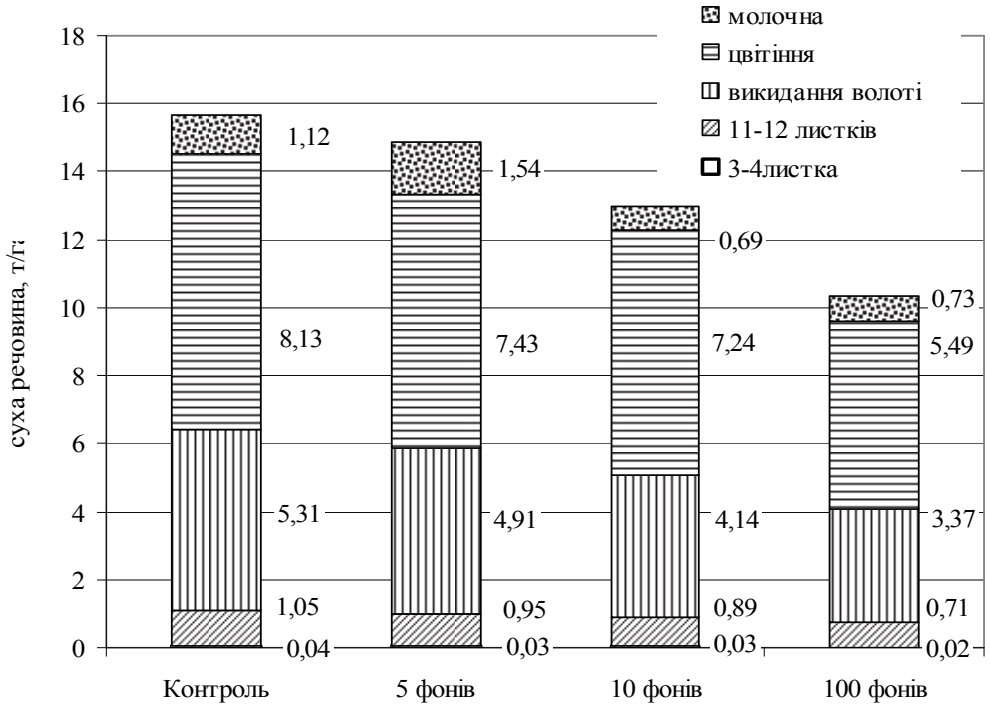

Figure 1. The accumulation of dry matter by corn plants during the interphase period, depending on the contamination of the agroecotope HM, t/ha (average for 2012–2014)

Optimality of the passage of photosynthetic processes is indicated by the amount of plastic substances created by the unit leaf surface of the sowing. In general, the PSC of corn crops averaged 6,55–8,46 g/m^2

per day over the years, depending on the amount of HM in the soil (Tabl 2) [8, 13]. It is known that during the vegetation period, the PSP can vary from 2 to 25 g/m^2 per days. In corn plants, a gradual increase in the productivity of photosynthesis was observed from the beginning of vegetation and reached a maximum in the phase of ejection of panicles – 11,18–14,33 g/m^2 per day. Then there was a sharp decline in this indicator.

2. Net productivity of photosynthesis of corn plants with different accumulation of HM soil, g/m^2 per day (average for 2012–2014).

Option of experience (pollution degree)	Phases of growth and development				NPP, g/cm^2
	3-4 leaves	10–12 leaves	Throwing out the whisk	Flowering	
1– natural background of HM (control)	3,61	9,81	14,33	6,08	8,46
4– five times the natural background of the HM	3,43	9,32	14,05	5,95	8,19
2 – a tenfold excess of the natural background of the HM	3,18	8,69	11,84	5,80	7,38
3 – hundredfold excess natural background HM	2,71	7,33	11,18	4,99	6,55
$\bar{X} \pm S\bar{x}$	*3,23*± *0,20*	*8,79*± *0,54*	*12,85*± *0,79*	*5,71*± *0,25*	*7,65*± *0,43*
V,%	*12,1*	*12,2*	*12,3*	*8,6*	*11,3*
S	*0,39*	*1,07*	*1,57*	*0,49*	*0,86*

The researchers found that the productivity of photosynthesis in corn plants is the highest for 25 days (50–70 days after emergence) [2, 7, 9]. In the same period, there is the greatest increase in the dry mass of plants [8]. Based on the results of our studies, the correlation between the accumulation of dry matter and NPP was close positive, as evidenced by correlation coefficients that were within the range of 0,747–0,998.

The productivity of assimilative work of the leaves characterized the reaction of plants to soil conditions. Net productivity of photosynthesis is optimal by assimilation of 4–6 g of organic substances per m^2 per day [8]. In spite of the high values of NPP sowings in our experiment, the increase in the content of HM in soil reduced this indicator by 3,2–22,6 % compared to the control, with a minimum productivity of NPP in the variant with a hundredfold excess of the natural background of heavy metals. The analysis of NPP for the phases of plant growth and development showed an average level of variability of the indicator depending on the contamination of the agroecotope HM. Only after reaching the phase of the panicle ejection, the difference between the variants decreased to a low variability. The negative changes in the development of the photosynthetic apparatus of corn sowings, revealed during the research, for increasing the content of HM in the soil are associated with the disruption of biochemical processes under the influence of cadmium, zinc, lead. It is known that chlorophyll has the ability to concentrate cadmium, although cadmium inhibits the formation of pigments of chlorophyll and anthocyanin leaves. The presence of about 96 mg of this element in 1 kg of leaves reduces the intensity of photosynthesis by 50 % [1, 12]. Lead to the violation of electron transfer reactions, reduces the activity of photosynthetic processes. The stimulating effect of lead relative to the introduction to plants of cadmium is an additional lever for reducing the efficiency of photosynthesis in corn [11, 14, 15]. It should be noted antagonistic interaction of zinc and copper, is their competition for the intake of the root system and can cause disturbances in biochemical processes in the plant organism [3].

The above is confirmed by the results of our previous studies on the qualitative indicators of the activity of chloroplasts – changes in the chlorophyll fluorescence parameters of corn leaves in the languages of soil contamination of HM [5]. The basic parameters of Kautsky's induction curve characterize the photosynthetic processes in chloroplasts, caused by the influence of the medium on the flow of both light and dark phases,

and testify to the resistance of plants to the action of unfavorable factors in man-made food fotogopes. Above the natural content of lead, zinc, cadmium in the soil, the key parameters changed: background fluorescence (Fo), maximum fluorescence yield (Fm), stationary fluorescence (Fst). And by their value, the efficiency coefficients of the primary processes of photosynthesis (Fv/Fm) and the efficiency of the Calvin cycle ((Fm-Fst)/Fst) were calculated. In contaminated areas, the induction of fluorescence, determined at the onset of 3–4-leaf phases, the ejection of the panicle, milk ripeness showed a 12–50 % decrease in the efficiency of the primary photosynthetic processes in corn, and the efficiency of the Calvin cycle is 13–43 % compared to the control.

The correlation analysis revealed a close positive relationship between the efficiency of the primary photosynthetic processes in the leaves of corn plants and the state of the photosynthetic apparatus, namely: the area of the leaf surface with the coefficients 0,805–0,985, the PSP by the coefficients of 0,753–0,971, the NPP of 0,777–0,963, in accordance with the phases Development (Table 3). The effectiveness of the Calvin cycle, determined from the parameters of the Kautsky curve, had a somewhat less close connection with the state of the assimilation apparatus. The coefficient of correlation with the area of the leaf surface was 0,672–0,940, the PSP was 0,588–0,923, and the PPP was 0,581–0,914. The tightness of communication increased with the transition to phases, which are characterized by the maximum development of photosynthetic apparatus in plants – ejection of panicle, milk ripeness.

3. Correlation dependence between the fluorescence parameters of leaf chlorophyll and the state of the assimilation apparatus of corn plants, average for 2012–2014.

Fluorescence parameters of chlorophyll	Phases of growth and development		
	3–4 leaves	Throwing out the whisk	Milk ripeness
Leaf surface area			
The efficiency of the primary processes of photosynthesis (Fv/Fm)	0,805	0,975	0,985
The effectiveness of the Calvin cycle ((Fm-Fst)/Fst)	0,672	0,824	0,940
Photosynthetic seeding potential			
The efficiency of the primary processes of photosynthesis (Fv/Fm)	0,753	0,974	0,971
The effectiveness of the Calvin cycle ((Fm-Fst)/Fst)	0,588	0,823	0,923
Net productivity of photosynthesis			
The efficiency of the primary processes of photosynthesis (Fv/Fm)	0,777	0,963	0,954
The effectiveness of the Calvin cycle ((Fm-Fst)/Fst)	0,581	0,792	0,914

The development of the assimilation apparatus and the productivity of its activities throughout the stages of plant growth and development determine the success of the processes of crop formation and its quality. In our studies it was proved that corn has a pronounced resistance to contamination of the upper 0–20 cm layer of soil with lead, cadmium and zinc, yielding yields of 6,15–7,93 t/ha. However, in all areas with a 5–100-fold increase in the background of the HM, the yield of corn cobs decreased by 0,52–1,78 tons/ha compared to the control, that is, yield losses were 6–22 % (Table 4).

4. Correlation between productivity and fluorescence parameters of leaf chlorophyll, indicators of the state of the assimilative apparatus of corn plants, average for 2012–2014.

Index	Photo-synthetic seeding potential	Net produc-tivity of photo-synthesis	Parameters of fluorescence of leaf chlorophyll according to developmental phases					
			The efficiency of primary photosynthetic processes (Fv/Fm)			The efficiency of the Calvin cycle ((Fm-Fst)/Fst)		
			3–4 leaves	Throwing out the whisk	Milk ripeness	3–4 leaves	Throwing out the whisk	Milk ripeness
Produc-tivity	0,995	0,978	0,737	0,977	0,979	0,604	0,850	0,928
Weight of 1000 grains	0,801	0,913	0,964	0,962	0,951	0,852	0,918	0,983

The results of the correlation analysis confirmed the close positive dependence of corn yield and the weight of 1000 grains on the state of the assimilative apparatus of plants determined by the PSP and PPF. It is important that the efficiency of the primary photosynthetic processes and the efficiency of the Calvin cycle also had a positive relationship with the yield of corn. The closest relationship between the parameters of fluorescence and yield is found in the phase of throwing the whisk and milk ripeness.

Conclusions

An increase in the content of HM in the soil caused negative changes in the development of the photosynthetic apparatus of corn sowing, which is associated with a violation of biochemical processes under the influence of cadmium, zinc, lead. For the contents in the upper 0–20 cm layer of gray forest soil of lead to 1000 mg, zinc to 500 mg of cadmium to 20 mg/kg, the photosynthetic potential of sowing was reduced by 7,5–34,2 %, the net productivity of photosynthesis by 3,22–22,6 %.

A close positive relationship was found between the qualitative and quantitative indicators of the state of the assimilative apparatus of corn plants in conditions of soil contamination with lead, cadmium and zinc. Coefficients of correlation between the efficiency of primary photosynthetic processes, determined by the method of induction of chlorophyll fluorescence, and the PSP were 0,753–0,971, the NPP was 0,777–0,963. The efficiency of the Calvin cycle, determined from the parameters of the Kautsky curve, had a correlation with the PSP – (0,588-0,923) and with the NPP – (0,581–0,914).

For the accumulation of lead up to 1000 mg, zinc to 500 mg of cadmium to 20 mg/kg in the upper 0–20 cm layer of soil, the reduction in the yield of corn cobs was 6–22 % compared to the control. The effectiveness of the processes of crop formation is determined by the development and productivity of assimilative soil contamination with HM. The correlation coefficients between the yield and these indicators were within the range (r = 0,978–0,995).

Bibliography

1. Artomonov V. I. Plants and cleanliness of the natural environment/V. I. Artomonov. – M., 1986. – P. 27–31.

2. Zolotov V. I. Productivity of corn in connection with photosynthetic activity of plants/V. I. Zolotov, A. K. Ponomarenko//Bul. Institute of corn. - Dnepropetrovsk, 1978. – № 2. – P. 13–15.

3. Kabata-Pendias A. Microelements in soils and plants/A. Kabata-Pendias, H. Pendias. – Moscow: Mir, 1989. – 440 p.

4. Karapetyan N. V. Variable fluorescence of chlorophyll as an indicator of the physiological state of plants/N. V. Karapetyan, N. G. Bukhov//Physiology of Plants. – 1986. – T. 33, № 5. –P. 1013–1026.

5. Korsun S. G. Induction of fluorescence of chlorophyll in corn leaves with heavy metals contamination/S. G. Korsun, V. V. Grush, N. I. Dovbash//Agroecological Journal – № 2. – Kyiv, 2015. – P. 36–41.

6. Methods of biological and agrochemical studies of plants and soils/[Z. M. Hrytsayenko, A. O. Grytsaenko, V. P. Karpenko and others.]. – K .: ZAO "NICHLAWA", 2003. – 320 p.

7. Mokrienko V. A. Improvement of elements of high technology of corn cultivation in the forest-steppe of Ukraine: author's abstract. Disser. work of the cand. of agricultural sciences: 06.01.09/V. A. Mokrienko – K .: NAU, 2004. – 22 p.

8. Nichiporovich A. A. Photosynthetic activity of plants in crops/A. A. Nichiporovich, L. E. Stroganova, M. P. Vlasova – Moscow: USSR Academy of Sciences, 1961. – 137 p.

9. Pochinok Kh. N. Intensity and productivity of photosynthesis and the use of solar energy by corn at different seeding density and nutritional status/Kh. N. Pochinok,. B. I. Gulyaeva, A. S. Okanenko et al.//Republican interdepartmental collection. – Kiev, 1965. – P. 21–24.

10. Yasonidi O. E. Photosynthesis with elements of mathematical programming of productivity of agricultural crops/Ed. O. E. Yasonidi. – Novocherkassk, 2007. – 52 p.

11. Cunningham L.M. Physiological and biochemical aspects of cadmium toxicity in soybean/L.M. Cunningham, F.W. Collins, T.C. Hutchinson//Conf. on Heavy Metals in the Environment (Toronto, 1975, October 27) – Toronto, 1975. – P. 97.

12. Küpper H. Cadmium-induced inhibition of photosynthesis and long-term acclimation to cadmium stress in the hyperaccumulator *Thlaspi caerulescens*/H. Küpper, A. Parameswaran, B. Leitenmaieretal.//New Phytologist. – 2007. – Vol. 175 (4). – P. 655–674.

13. Monnet F. Photosynthetic activity of *Lolium perenne* as a function of endophyte status and zinc nutrition/F. Monnet, N. Vaillant, A. Hitmi, H. Sallanon// Functional Plant Biology. – 2005. – Vol. 32. – № 2. – P. 131–139.

14. Photosynthetic activities of cadmium-treatedtomato plants/T. Baszynski, L. Wajda, A.T. Krol et al.//Physiol. Plant. – 1980. – Vol. 4. – P. 365.

15. Sharma S. Cd phytotoxicity to barley (*Hordeum vulgare*) as affected by varying Fe nutritional status/S. Sharma, S. Kaul, A. Metwallyetal.//Plant Science. – 2004. – Vol. 166. – № 5. – P. 1287–1295.