UDC 633.15:631.81.095.337](477)

ASSESSMENT OF THE MICROELEMENTS CONTENT IN CORN PLANTS IN STEPPE ZONE OF UKRAINE

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The data on microelement composition determination of corn plants in the Steppe zone of Ukraine are summarized. The averages of microelements content in grain, foliage and stems mass are determined. Maximal values of biological uptake index in the corn grain are marked for Zn (30,5) and Cu (11,1). The analysis of empirical curves specifies that action of the certain factors does not allow corn to realize completely potential opportunities on accumulation of the majority of microelements. The gradation scale of the microelements contents in the grain is offered in view of regional features.

Key words: *corn, microelements, contents, variability*

Introduction. In recent (2000-2010) years, role of corn in grain-farming industry is advancing, as evidenced by the increase in: sowing area, by 2.1 times (from 1.278 to 2.648 mio ha), average yield, by1.5 times (from 3.01 to 4.51 t/ha) and gross yield of grain, by 3.1 times (from 3.85 to 11.95 mio tons) [1]. Along with goal to increase the yield-rate, a great attention should be focused on obtaining high-grade bio- products generally classified by a system of assessment indices [2, 3]. One of these indices is a chemical composition of plants, including micro-elemental (ME) contents.

Specifics of plants' ability to accumulate MEs are now known quite enough, but under present-day conditions and climatic, genetic, man- caused etc. factors, the dynamics of chemical elements- uptake by plants, phylogenetically attributed to each floral species, undergoes an active changeover. Bibliography sources reveal a controversy of data on contents and distribution of MEs among commercial and non-marketable batches of harvested corn grain. There exist many examples of ME-concentrations' variability in major crop products. In some cases, discrepancy of ME-contents in crops' generative organs amounts to tens and even hundreds of times, indicating that elemental content- stability of grain is a rather conditional notion [4, 5, 6].

Due to the fact that soil and climate conditions greatly affect indices of biological value of food and feed products, the goal of this study is to assess micro-elemental contents and to reveal peculiarities of ME- distribution in corn plants, in Ukrainian Steppe zone conditions. This tool would enable one to determine constant and variable factors of ME- contents variability in grain and bulk of leaves and stalks, and to identify vectors of these changes. Thus obtained data would help diagnosing a status of the soil-plant system to define an adequacy of micro-elements' contents, along with ecological crop-yield purity.

Methodological principles of work. Amount of Mn, Zn, Fe, Cu, Co, Ni, Pb and Cd contents in corn grain and bulk of leaves and stalks was evaluated by aid of atomic-absorption C-115M1™ spectro-photometer via acetylene-air flame techniques. Experimental data were processed by Excel- 1998™ math-statistical method and using Statistica™ (Version- 6) software. An array of analytical data on microelement contents in corn-plants, derived over the past 25 years in field experiments by the Institute of Agriculture of Steppe Zone, were statistically processed; said data cover the most typical soil variations and reflect climatic peculiarities of Northern part of Ukrainian Steppe.

Results and discussion. Results of processing enabled authors to calculate numerical data of ordered series of ME- contents in corn grain and bulk of leaves and stalks, and to define their averaged parameters as well. Average values of ME-concentrations in corn-grain include: Zn-17.7; Mn-3.85; Cu-2.15; Co-0.30; Ni-0.82; Fe-32.4; Cr – 0.48; Pb-0.39; Cd – 0.017 mg/kg dry matter (Table 1).ME-distribution- chain in corn-grain looks like: Fe> Zn> Cu> Mn> Ni> Cr> Pb> Co> Cd. Among all elements, maximum share falls on Fe (~50 %), then Zn (~30 %), Cu and Mn (4-7 %) and, eventually, Ni, Cr, Pb, Co, Cd (below 1 %). A notable Fe-, Zn-, Mn- and Cu- contents in grain is related to their mission to synthesize protein, chlorophyll and vitamins. Thus calculated coefficients of variation and average error reveal an existence of fluctuations in values of corn- grain elemental contents. So, most elements (Mn, Cu, Co, Fe, Pb, Cd) were noted for high variability [V], whose indices made up 29.8 - 48.1 % range. Zn-contents (V= 15.5 %) is the most stable, while Cd has an easily- variable index. Deviations between extreme values of ME- contents in corn-grain made up 2-10 times.

Table 1. Contents of microelements in corn plants at full maturity-phase

Element	N	$\bar{x}$	lim	V	$\bar{x}$	lim	V
		Grain			Leaves & stalks bulk		
Zn	218	17.7	10.4-25.8	15.5	12.4	3.69-36.5	51.6
Mn	243	3.85	1.27-9.80	44.6	25.7	3.30-76.10	57.1
Cu	243	2.15	0.60-5.71	44.9	3.52	1.02-10.60	57.2
Co	231	0.30	0.15-0.72	34.2	0.79	0.30-1.66	37.6
Ni	214	0.82	0.42-1.86	29.8	1.46	0.64-3.88	44.4
Fe	63	32.4	18.4-60.0	30.7	101	44.8-159.0	31.8
Pb	220	0.39	0.14-0.80	39.0	1.12	0.25-2.83	50.0
Cd	156	0.017	0.006-0.068	48.1	0.073	0.012-0.317	92.6
Cr	68	0.49	0.22-0.89	31.9	1.94	0.40-7.75	92.3

Notes: N – sample scope; $\bar{x}$ - average value, mg/kg dry matter; lim – (min – max) fluctuations limit, mg/kg dry matter; V – variation index, %

ME- contents' fluctuations in corn leaves and stalks bulk exceeded those in corn grain, with the following average values: Zn-12.4; Mn– 25.7; Cu– 3.52; Co– 0.79; Fe-101; Cr- 1.94; Ni- 1.46; Pb – 1.12; Cd – 0,073 mg/kg of dry matter. ME-distribution in by- products was slightly different, chaining like: Fe> Mn> Zn> Cu> Cr > Ni > Pb > Co > Cd. Unlike grain, leaves and stalks bulk contains by far more Mn (17% out of 100% for all MEs); while amount of Zn and Cu is the same as in grain; whereas toxic elements (Pb, Cd, Ni, Cr) are mostly accumulated within by- products proper. Yet the highest value (66 %) is won by Fe, being accumulated in large amounts both in grain and vegetative bulk of corn. Statistical analysis of ME-contents in by-products reveals an intensive variability of relevant data, backed up by a broad scatter of variation index (V= 31.8-92.6 %). Difference between extreme values of ME- contents within vegetative bulk makes up 4-25 times.

All plants are known for their ability to selectively uptake and concentrate chemical elements required for their growth and development, whereby ME-proportions in plants differ from those in soils. To evaluate intensity of ME uptake by corn plants in Steppe zone conditions, authors suggested a set of 'Biological Uptake' indices (BUI).

BUI- values in grain differ from those in bulk of leaves and stalks, and this fact presumes an existence of an interface- barrier between plants' vegetative and generative organs for practically all elements but Mn (Table 2). Corn is characteristic with its ability to intensively absorb Zn, Cu and Cd from soil with their top BUI-values (> 3); somewhat lower for Pb, Co, Ni (> 1) and the least for Fe and Mn (< 1). High BUI-indices for Zn and Cu (on contrast to their scantiest concentrations in soil) reflect their high biological activity and physiologic importance for corn-plants.

Table 2. Coefficients of biological uptake of microelements by corn plants

Kind of products	Zn	Mn	Cu	Co	Ni	Fe	Pb	Cd
Grain	30.5	0.73	11.1	2.70	2.90	0.12	2.36	5.69
Leaves and stalks bulk	4.79	1.09	4.10	1.60	1.16	0.08	1.52	5.62

Analysis of statistical ordered series ensures an important information from plotted empirical curves of ME-contents' distribution-frequency, both spatially (Steppe zone) and over 25-years' time. Figures 1 to 4 show empirical curves plotted on data of Zn, Mn, Cu and Pb distribution in corn grain. Thus, Zn-content distribution is naturally symmetrical, testifying its non-dependence on factors of soil and climatic conditions with 99 % probability.

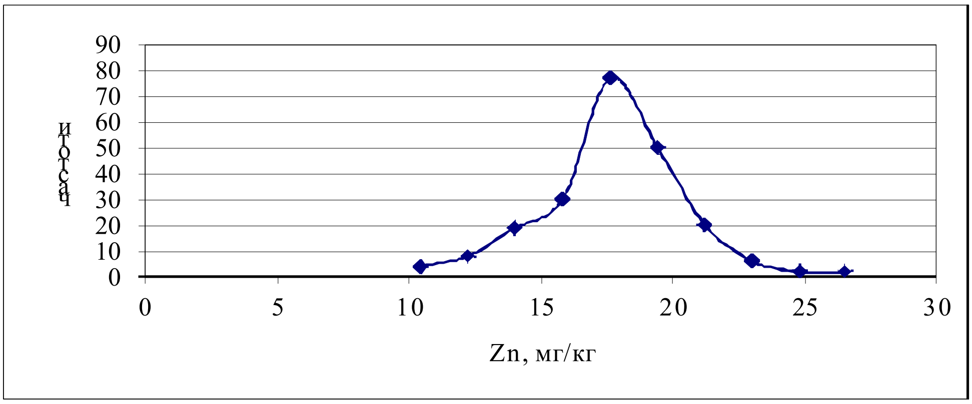

Figure 1: Empirical curve of Zn- content distribution in corn grain

At the same time, statistical analysis of Mn, Cu, Co, Nì, Fe, Pb and Cd contents in corn grain has confirmed authors' assumption that experimentally modeled rates and real distribution facts might mismatch, thus referring to a "mixed" type of variation. These data- summations are non-uniform and may consist of several normal aggregates. The distribution law- hypothesis can be validated via values of asymmetry (As) and excess (Ex) indices and/ or using statistical tables as well. These data-items possess clearly obvious right-hand asymmetry and multi-directional Ex- indices. Such the "mixed" variations in time and space are not amenable to preliminary computations, hampering the work on sites studied. Therefore, each data-item requires its own empirical curves' analysis. Due to biblioraphy sources and judging from mathematical viewpoint, «mixed» variation curves differ from those of normal Gaussian distribution, yet splitting «mixed» curves in several asymmetric sections is not impossible.

Empirical curve of Mn- distribution in corn- grain is normally asymmetrical. Graphically, positive asymmetry appears as a variation curve with its left-hand off-center distribution- peak. The kurtosis rate (Ex= 1.21) outstrips the critical value (0.826) in terms of significance level (ά= 0.01). Values of As and Ex thus obtained testify that real distribution has right-hand asymmetry and a clearly expressed kurtosis (Figure 2). A medium arithmetic value for manganese is 3.85 mg/kg; however, the most typical mark is 3.19 mg/kg. Hence, this empirical curve shows downward- shifting values of Mn- content in grain. This fact indicates an existence of lots of factors that limit manganese- income to corn-grain.

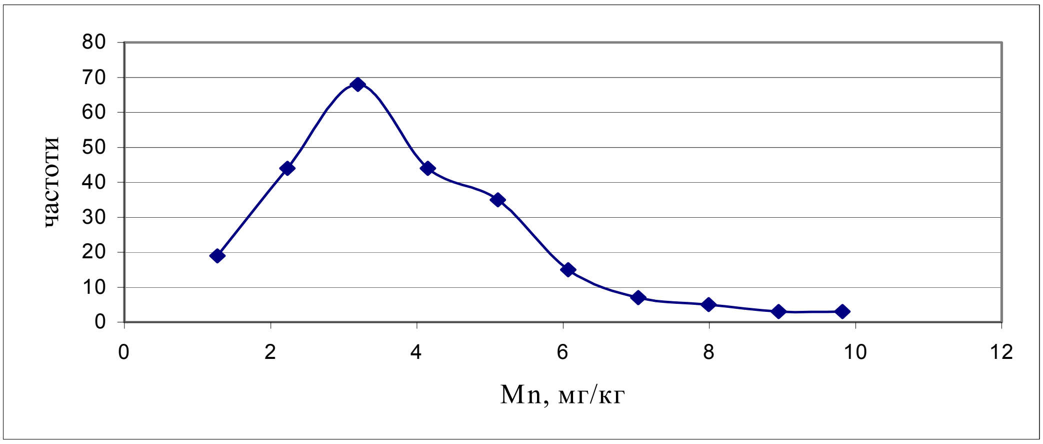

Figure 2: Empirical curve of Mn- content distribution in corn grain

The empirical curve of Mn- content distribution in corn grain has either two peaks of positive asymmetry and negative kurtosis, or consists of two normal distributions (Figure 3).

This fact can be explained by (i) either significant spells of climatic conditions that affect an availability of copper for plants or (ii) genetic diversity of corn hybrids that can also affect the elemental composition of grain.

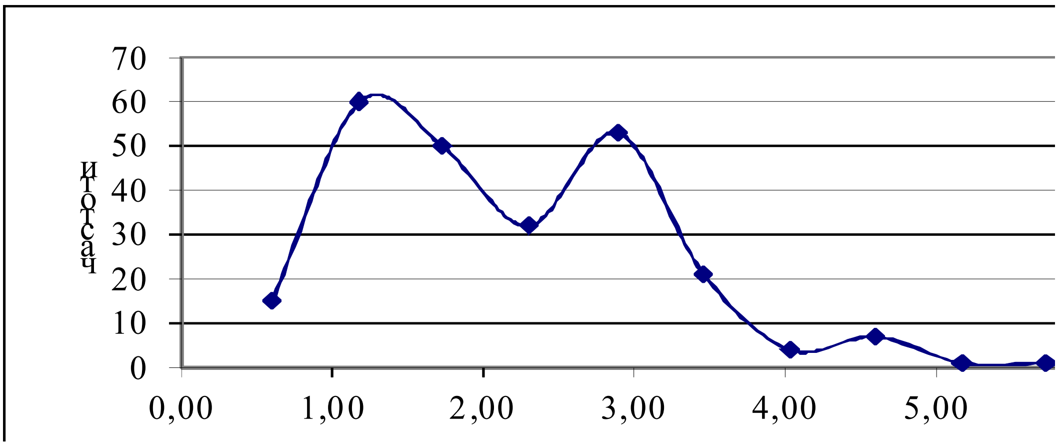

Figure 3. Empirical curve of Cu- content distribution in corn grain

The cobalt – plotted empirical curve distinctly demonstrates its positive asymmetry index (As = 0.90), whereby the curve- peak is faced towards decrease of Co- content in corn- grain (probably, due to a reduced availability of Co in soil). However, ordered-series analysis shows a weakly expressed positive kurtosis (Ex= 0.29) vs critical value (Ex= 0.823). Such an asymmetry distribution-value can not tolerate the normal distribution law with 99% probability.

Variation curve of Ni- distribution in grain has significant asymmetry (As) and excess (Ex) values. This indicates a considerable Ni-content variation in corn grain in most regions of Steppe zone.

Both indices for Fe make up: As= 0.881 and Ex= 0.058, while its distribution can not obey the normal distribution law with 99% probability. The weakly expressed negative K- excess is caused by vast areas of arable lands with different amounts of Fe- forms available to corn-plants.

A similar law was also observed for content of Pb (with critical values of As= 0.60 and Ex=0.43), along with two clearly defined peaks on "mixed" type variation curves (Figure 4).

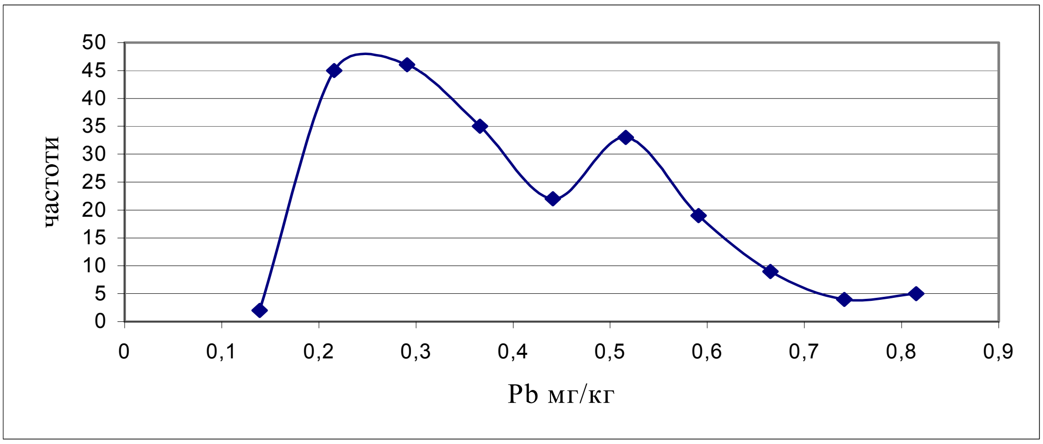

Figure 4: Empirical curve of Pb- content distribution in corn grain

Empirical ordered series of Cd have a significant negative kurtosis (Ex= 95) and a slightly positive asymmetry (As = 0.16). Cadmium-accumulation in corn grain is specified by certain objective factors that vary in space and with time.

As noted above, parameters of corn- plants elemental composition are prone to fluctuations, which fact complicates an assessment of a crop-nutrition balance. Therefore, authors exercised to sketch up a gradation scale for ME- contents in grain, using methods of statistical analysis and spatial interpretation of results, and taking into account certain regional peculiarities as well (Table 3).

Table 3. Parameters of ME contents in corn grain

Level	ME- contents, mg/ kg dry matter						
	Zn	Mn	Cu	Co	Ni	Pb	Cd
Low	9.5-15.1	0.79-3.79	0.31-2.10	0.113-0.280	0.337-0.850	0.100-0.337	0.0048-0.0123
Medium	15.2-21.9	3.80-7.37	2.20-4.24	0.281-0.485	0.860-1.470	0.338-0.619	0.0124-0.0213
High	22.0-26.5	7.38-10.20	4.25-6.00	0.486-0.652	1.480-1.990	0.620-0.852	0.0214-0.0288

Calculation of averaged numerical characteristics (medium value, variance etc.) of ordered series of ME-contents in grain becomes possible after replacing interval series by interval-free series.

Thus computed medium (central) values for each class appear as ordered series that enable one to calculate mathematically trustworthy levels of ME-contents in basic products, using such a statistical indicator as the 95% confidence- interval of medium (central) values for each class. Application of the confidence interval for central values allows one to define three statistically reliable levels of corn grain- supply with micro- elements.

Medium level covers all values within the confidence interval with 95% probability:

$$\pm 1.96\ S\bar{x}$$

The low level is less than:

$$- 1.96\ S\bar{x}$$

The high level is above:

$$+ 1.96\ S\bar{x}$$

where: $\bar{x}$ is an average of central values of each class;

$S\bar{x}$ is a medium error;

t =1.96 is the normalized deviation at 95% probability (P).

An adequate statistical processing, beside showing how averaged Steppe- zone results normalize statistically reliable differences between ME-contents in grain under influence of all factors' summation, is also demonstrating the nature of changes in space and time for the contents of each element studied.

Conclusion. Contents of micro-elements in corn grain, leaves and stalks are characterized by significant fluctuations. Contents of Mn, Cu, Co, Fe, Pb, Cd in grain are notably variable (V= 29.8 to 48.1%). Content of Zn (V= 15.5%) is characterised by its stability. The facts below are the background data of the Ukrainian Steppe Northern sub-zone.

Maximum BUI- values for corn-grain belong to Zn (30.5) and Cu (11.1).

Less intensively uptaken from soil are Ni (2.90), Co (2.70), Pb (2.36), Mn (0.73) and Fe (0.12).

Analysis of ordered series of ME-contents in corn grain has allowed authors to detect an existence of three (single-modal, transient and bimodal) kinds of probability functions. Their dynamic evolution is defined by internal fluctuations (i.e., genetic factor) and environmental conditions' variability. The most stable status is typical with single-mode positive asymmetry functions, indicating that plants fail to completely use their potential advantages to stock up Mn, Cu, Co, Fe, Pb, Cd in grain, under a given zone conditions.

The confidence interval of central values enabled authors to define statistically reliable levels (low, medium and high) of ME- contents in corn grain.

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Received by Editorial Board 21.07.2013