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CORRELATION OF THE STRUCTURAL TRANSFORMATION INDEXES IN PLANTS UNDER METAL STRESS CONDITIONS

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Peculiarities of structural plasticity in plants from Donbass's industrial ecotopes were examined within rhizological, caulillogical and foliologial aspects. The 6 basic correlation groups are determined, being relatively morpho-physiologically homogenous and showing identical tendencies of the tissue reaction to the metal pollution. Polymorphism of grassy plants, for example *Cichorium intybus* L. and *Tripleurospermum perforatum* (Merat) M. Laipz, has demonstrated an adaptive character, at may be used in testing of a soil contamination by heavy metals.

Key words: structural plasticity of plants, metallic pollution, phytoindication.

On account of their intensive coming to the atmosphere and of their toxicity, heavy metals are the most dangerous ingredients of the industrial emissions [2, 8, 10]. The anthropogenous dispersion of these toxicants into the biosphere causes changes of the natural biochemical circulation of elements. More then 80% of pollutants of the metal nature are considered to be of anthropogenic origin [4, 10]. Emitted metals are accumulated in the first instance within the upper soil horizons wherefrom they migrate into another compartments of natural environment [5].

Under polluted by industrial emissions conditions the plants' tolerance is provided by the peculiarities of the cover and interior tissues structure in root, stem and leaf, preventing the toxicants penetration into the plant and their distribution inside it, namely: xeromorphism, revealing Itself in thickening of the epidermis, cuticular layer, wax deposit, as well as in dense arrangement of the interior conformation tissues [3, 4, 6, 7, 13]. Quantitative signs of characteristics appearing as a consequence of the exogenous chemical substances' impact could be more correctly called painomorphic rather than xeromorphic, since they occur as a result of non specific pollutostress [12, 16, 18]. In connection with necessity of global monitoring, a special attention among biological methods of environmental state assessment for the large areas is attached to the use of indicational potentialities of plants [2, 13, 17, 18]. In this connection, the present work deals with the correlation of phytoindicating indices histological organization of and the range

of characteristics' variation to the degree of metal stress upon the rhizodaphosphere of the northern industrial center area of the Donetsk economical region.

The experiment was carried out in the Artemovsk and Kramarorsk-Konstantinovka industrial junction area of Donbass (Ukraine), where a 302-componental monitoring network was laid out by us. Data for the analysis of the structural indices of the root, stem and leaf of *Cichorium intybus* L. and *Tripleurospermum perforatum* (Merat) M. Laipz (*Asteraceae* Dum.) were obtained from the 80 module points which are the most convenient ones as for homogeneous edapho-climatic conditions, that meets the requirements of the general phytoindicational monitoring in the industrials areas.

The points for extracting the soil assays were chosen depending on the high metal concentrations zonation, for example, the Artemovsk Non-ferrous Metal Plant (Zone 1), the Artemovsk Maschine Building Plant „Pobeda Truda” (2), the central city ore-mining complex of Artemovsk (3), Chasov Yar Fireproof Industrial complex (4), Uglegorsk Hydro-electric Power Station (5), „Uzhnyi” Production Union One-mine (6), the Konstantinovka Mechanized Glass-factory (7), the Konstantinovka „Ukrzink” Plant (8) or in correspondence with the control background conditions a rural Serebryanka built-up area (9), Protected Landscape of the Artemovsk Distance of the Protective Forest Plantations (10). Furtheron, information will be presented according to this numeration.

Metal concentrations in the soil and vegetation assays were measured applying the ato-mic-and absorptive spectrophotometry method on the apparatus of „Saturn-3” and x-radiation fluorescence on the „Spectroskan” at the Donetsk Botanical Garden of the National Academy of Sciences of Ukraine laboratory. Structural indices are measured with the help of light microscopy on the Ergaval microscope [1].

Peculiarities of the structural organization of the test plants' vegetative organs were determined upon the literary sources for the rootage [9, 14, 15, 17, 20, 21], leaf [7, 14, 19], stem [7, 9, 14] and under local standards [6, 13]. The whole range of index variation or of the calculated information-and-indicator indexes was divided by us in 10 intervals with the aim of performing the phytoindicational assessment after the 10-mark scale and of elucidation the degree of correlation links between the plants' plasticity and the levels of soil pollution with some heavy metals and arsenic [13]. The degree of correlation was determined with the help of 2 alternative methods: calculation of the correlation coefficient (r) and general overlapping areas of the territories by way of superposition of the pollution and histotransformation chars, corresponding to the half-interval 5 after the mark-and scale mathematics modeling, that is indicated in percentage of the possible maximum one (S , %). All the 80 blocks of comparison underwent the statistic working out. To the discussion only the results upon the 1997-2001 years are presented, that ensures the 95% trustworthiness on the confidential level. In the tables, as an example, the result for 10 module zones are allocated and indexes are calculated for the whole of 80-componental block.

Phenotypic variation is proved as a result of obtaining the structurally stable forms in the next three populations in the cause of growing under control conditions.

Pollution by some heavy metals of soils of the zones under investigation is indicated in the tables 1, 2. The specifics of the metal character of pollution is determined by

the high background levels for the natural metalogenic induction zones as well as by the location and functioning by industrial plants.

Table 1

Lead, Zinc, Cadmium, Nickel and Chromium contents in the Artemovsk and Kramatorsk-Konstantinovka industrial junctions' soils (mg/kg of the dry mass; $M\pm m$; $n=5$)

N ^o module zone	Pb	Zn	Cd	Ni	Cr
1	425.8±0.95	515.0±1.71	6.49±0.01	197.2±4.27	253.2±6.62
2	115.4±0.50	518.4±2.26	6.51±0.01	164.0±9.21	180.7±4.49
3	103.7±1.52	497.7±8.75	2.27±0.13	165.0±5.00	199.8±7.00
4	7.6±0.02	299.3±0.85	0.39±0.01	143.0±3.43	103.9±4.74
5	83.9±0.86	443.3±1.61	0.41±0.15	14.9±0.01	83.0±1.45
6	90.7±3.83	403.9±10.7	1.03±0.01	21.3±0.03	93.4±0.15
7	987.2±11.1	396.8±1.66	1.48±0.01	134.9±3.03	247.0±5.93
8	850.4±0.42	966.1±2.31	1.55±0.01	189.0±6.47	261.1±6.68
9	72.9±0.40	205.7±0.84	0.42±0.01	44.3±0.14	96.9±1.21
10	81.8±0.72	253.0±5.83	0.42±0.01	43.2±0.74	72.2±1.75

Table 2

Molibdenium, Tin, Iron, Manganese and Copper contents in the Artemovsk and Kramatorsk-Konstantinovka industrial junctions' soils (mg/kg of the dry mass; $M\pm m$; $n=5$)

N ^o module zone	Mo	Sn	Fe	Mn	Cu
1	1.52±0.01	10.72±0.03	69.78±0.03	1070.7±6.1	531.7±3.9
2	1.17±0.07	6.70±0.01	60.24±1.44	903.2±4.3	487.0±13.2
3	2.91±0.09	4.00±0.02	65.92±0.14	904.9±5.3	371.2±6.6
4	1.74±0.02	2.77±0.01	57.13±3.29	757.1±3.7	294.2±3.9
5	2.52±0.01	5.85±0.01	27.21±0.13	748.0±7.2	40.3±0.01
6	1.25±0.01	10.57±0.03	30.13±0.42	3158.2±10	38.6±0.01
7	1.43±0.01	22.88±0.14	61.78±0.25	709.0±2.1	276.2±10.1
8	1.44±0.08	23.04±0.14	41.58±0.28	834.9±11.2	401.2±4.7
9	0.92±0.01	0.97±0.01	27.49±0.01	703.6±3.1	24.1±0.0
10	0.74±0.03	4.71±0.02	27.14±0.03	695.4±3.7	30.6±0.1

It is append from the tables 1 and 2, that concentrations of certain heavy metals in the soils of ecological disastrous zones exceed by several times the control background levels.

Studies of the histostructural peculiarities of the rootage during all stages of ontogenesis were performed after the following indices:

- 1) degradation of the peripheral part of dermatocalyptrogen on the initial stages of growing – the ratio of number deformable or transphormaticable cells of number high-grade dermatocalyptrogen tissues (DD);

- 2) stimulation of columella formation not of the apical initial cells, but of basal cells of the center of sleeping cells - the ratio of number meristemal center of sleeping cells of number apical initial cells (SC);
- 3) multiserial structure of rhizoderm – if number layer of a rhizoderm more then three(MR);
- 4) thickening of the external layer, winding of the unicellular layer of the tissue – authentic increase number cells of a external layer (TE);
- 5) amount of intercellular stomas of the primary cortex – the common range of quantity of cells was divided into 10 part (AI);
- 6) summary index of the small-cellularity – number cells in one field of vision of a microscope (ISr);
- 7) index of the radial growth of the meristematic zone - the ratio of occurrence of new cells on radius of a root to their general number on an axis (RGr);
- 8) heterogeneity index of the tracheal elements – above if the mistake of average arithmetic is more than sizes of cells (HTr);
- 9) deformation index of the terminal phloem – ratio abnormal elements of phloem to normally formed (TPr);
- 10) habitual asymmetry of root – degree of expressiveness of increase heterogeneity in the rather causal image concerning a frontal plane (HAr).

The tables 3, 4 represent the results of investigations of the structural organizations of test-objects.

Table 3

Structural organization of the *C. intybus* rootage

№ module zone	Indexes									
	DD	SC	MR	TE	AI	ISr	RGr	HTr	TPr	HAr
1	10	5	9	9	8	10	3	9	10	10
2	10	6	4	10	7	8	7	4	7	5
3	6	5	5	6	7	8	7	5	5	3
4	1	3	3	1	6	6	9	3	4	1
5	2	4	2	2	5	1	9	2	2	4
6	3	4	2	3	10	2	1	2	1	10
7	4	4	9	4	4	5	9	8	4	10
8	4	10	10	4	4	9	7	10	6	10
9	2	1	2	2	1	2	8	2	1	1
10	1	2	1	1	3	2	10	1	1	3
Me	Cd	Zn	Cr	Cd	Mn	Ni	Mn	Cr	Cu	Sn
+ r x 100	62	79	76	67	57	52	94	95	92	55
S, %	74	82	72	67	62	51	94	95	96	56

Me – metal.

Table 4

Structural organization of the *T. perforatum* rootage

№ module zone	Indexes									
	DD	SC	MR	TE	AI	ISr	RGr	HTr	TPr	HAr
1	10	6	10	10	9	10	3	9	10	10
2	10	6	7	9	7	9	9	4	6	7
3	6	5	7	5	6	8	7	5	5	8
4	1	4	6	1	5	6	9	4	4	5
5	2	4	1	1	4	1	9	2	2	1
6	3	4	1	3	10	2	1	1	1	1
7	4	4	5	4	4	5	9	8	4	5
8	3	10	9	3	3	9	7	10	6	2
9	1	1	2	1	1	2	8	2	1	1
10	1	1	2	1	3	2	10	1	1	1
Me	Cd	Zn	Ni	Cd	Mn	Ni	Mn	Cr	Cu	Fe
+ r x 100	67	73	92	70	55	50	93	90	90	57
S, %	78	75	97	72	64	51	92	92	87	50

The closed correlational dependence is determined for deformation indexes of the terminal phloem, heterogeneity index of the tracheal elements and the radial growth of the root meristematic zone.

Within the frames of heteromorphological and caulillogical aspects of phytoindication-al assessment the following indexes were used:

- 1) intensity of the stem indumentum – the number trichome (all range variability was divided on 10) (ISI);
- 2) presence of the pronounced costas – the attitude of an acuteness of a corner from 130 up to 30 degrees (PC);
- 3) thickness of the epidermal layer - all range variability was divided on 10 (EL);
- 4) multiserial structure of the chlorophyll-bearing parenchyma if number layer of a rhizoderm more than three (MC);
- 5) summary index of the small-cellularity of lacunar collenchyme and parenchyma of the primary cortex - number cells in one field of vision of a microscope (ISs);
- 6) presence of the pronounced fascicular cambium – by quantity of cells cambium between bunches (PFC);
- 7) the degree of fascicular cambium formation – on reduction of quantity of cells cambium in bunches (FFC);
- 8) small-cellularity of the meta- and protoxylem - number cells in one field of vision of a microscope (SX);
- 9) integrity of the phloem fascicles - by quantity of breaks in sigh a microscope (PF);
- 10) anomaly of the habitus, heteroramy – degree of expressiveness of increase heterogeneity in the rather causal image concerning a frontal plane (HAs).

Table 5

Structural organization of the steam of *C. intybus*

№ module zone	Indexes									
	ISI	PC	EL	MC	ISs	PFC	FFC	SX	PF	Has
1	9	9	9	9	10	3	5	9	10	4
2	10	10	10	5	8	7	6	4	7	1
3	6	6	6	5	8	7	5	5	5	1
4	1	1	1	4	7	9	4	3	4	1
5	2	2	2	2	1	10	4	2	2	1
6	3	3	3	1	2	1	4	2	1	1
7	4	4	4	9	5	9	4	8	4	10
8	4	4	4	10	9	7	10	10	6	8
9	3	2	2	2	2	8	1	2	1	1
10	1	1	1	1	2	10	2	1	1	1
Me	Cd	Cd	Cd	Cr	Ni	Mn	Zn	Cr	Cu	Pb
+ r x 100	58	60	67	59	51	93	97	91	93	92
S, %	57	67	67	60	56	90	98	90	97	93

Table 6

Structural organization of the steam of *T. perforatum*

№ module zone	Indexes									
	ISI	PC	EL	MC	ISs	PFC	FFC	SX	PF	Has
1	9	10	10	10	10	3	3	9	10	4
2	10	9	9	8	9	7	7	5	6	1
3	5	5	5	7	8	7	7	5	5	1
4	1	2	1	6	5	9	10	5	4	1
5	2	1	1	1	1	9	9	2	2	1
6	3	3	3	2	2	1	1	1	1	1
7	4	4	4	5	5	9	9	8	4	10
8	4	3	3	9	9	7	7	10	6	8
9	3	1	1	2	2	8	8	2	1	1
10	1	1	1	2	2	10	10	1	1	1
Me	Cd	Cd	Cd	Cr	Ni	Mn	Mn	Cr	Cu	Pb
+ r x 100	55	58	70	53	52	92	91	82	87	91
S, %	50	67	72	57	59	91	93	71	82	93

In the tables 5 and 6 the results of the investigations of the plant stem plasticity are presented.

As the most informative, characteristics such as the degree of fascicular cambium formation, of integrity of the phloem fascicles, and of anomaly of the stem habitus were defined; that determines the plant's general asymmetry.

Organisation of the *C. intybus* and *T. perforatum* lamina structural elements (tables 7, 8) was assessed after the following indexes:

- 1) the amount of the morphogenetic centers – quantity the new structural cells in epidermis (AMC);
- 2) atypically of stomatal-closing apparatus – the number abnormal elements stomatal-closing apparatus (SA);
- 3) reformity of epidermal cells by quantity alive cells in epidermis (RE);
- 4) thickness of the chlorophyll-bearing parenchima - all range variability was divided on 10 (TC);
- 5) summary index of the small-cellularity - number cells in one field of vision of a microscope (ISI);
- 6) index of the anomalyty of anastomosis – quantity abnormal dichotomical divisions on vessels (AA),
- 7) index of the radial growth of the meristematic zone - the ratio of occurrence of new cells on radius of a leaf to their general number on an axis (RGI);
- 8) heterogeneity index of the tracheal elements - above if the mistake of average arithmetic is more than sizes of cells (HTI);
- 9) deformation index of the leaf terminal phloem - ratio abnormal elements of phloem to normally formed (TPI);
- 10) heterophylia of the medial formation of lamina leaf - degree of expressiveness of increase heterogeneity in the rather causal image concerning a frontal plane (HAI).

Table 7

Structural organization of the lamina leaf of *C. intybus*

№ module zone	Indexes									
	AMC	SA	RE	TC	ISI	AA	RGI	HTI	TPI	HAI
1	5	10	4	9	10	9	3	9	10	5
2	6	8	1	5	8	10	7	4	7	5
3	5	8	1	5	8	6	7	7	5	5
4	2	6	1	4	7	1	9	5	4	2
5	4	1	1	2	1	2	9	1	2	4
6	3	2	1	1	2	3	1	2	1	3
7	4	5	10	9	5	4	9	8	4	4
8	10	9	9	10	9	4	7	10	6	10
9	1	2	1	2	2	3	8	2	1	1
10	2	2	1	1	2	1	10	1	1	2
Me	Zn	Ni	Pb	Cr	Ni	Cd	Mn	Cr	Cu	Zn
+ r x 100	90	62	76	52	52	97	94	92	92	50
S, %	95	60	72	51	54	95	97	93	94	60

Table 8

Structural organization of the lamina leaf of *T. perforatum*

№ module zone	Indexes									
	AMC	SA	RE	TC	ISI	AA	RGI	HTI	TPI	HAI
1	5	5	4	10	10	9	3	9	10	5
2	6	3	1	8	9	10	9	4	6	6
3	5	10	1	7	8	5	7	7	5	6
4	2	6	1	4	5	1	9	5	4	2
5	4	8	1	2	1	2	9	1	2	4
6	3	3	1	1	2	3	1	2	1	3
7	4	4	10	9	5	4	9	8	4	4
8	10	4	9	10	9	4	7	10	6	10
9	1	2	1	2	2	3	8	2	1	1
10	2	1	1	1	2	1	10	1	1	1
Me	Zn	Mo	Pb	Cr	Ni	Cd	Mn	Cr	Cu	Zn
+ r x 100	87	61	70	49	51	92	92	91	87	54
S, %	90	60	68	51	50	87	90	87	91	62

On the ground of the tables' 7 and 8 data It is determined, that correlation links are the closest one for indexes of the radial growth of the meristemal zone of lamina, for index of the anomaly of anastomosis, heterogeneity of tracheal elements and deformation of the terminal phloem and the amount of the morphogenetic centers.

Structural organization of the plant organisms is affected by the complex of factors [11], which we conditionally neglect in account of the relative heterogenous of stability of the selected samples.

Basing on the tables 3-8 and the results of investigation, the following regularities of correlation in blocks of structural changes of the metallogenic origin.

- 1) The indexes degradation of the peripheral part of dermatocalyptrogen on the initial stages of growing, of thickening of the extern layer, winding of the unicellular layer of the tissue, presence of the pronounced costas of stem, of the intensity of Its indumentum, and of thickness of the epidermis depend on the cadmium content in soil, though modification of the epidermal cells of lamina correlates with lead content.
- 2) Stimulation of columella formation and the amount of morphogenetic centers of lamina closely correlates with zinc content in the soil.
- 3) Within the chlorophyll-bearing tissues' transformation block the basic influence is that of chromium.
- 4) The amount of intercellular stomas of the primary cortex, indexes of the root and leaf radial growth and the amount of the pronounced interfascicular cambium are in close correlation with presence of manganese in the environment.
- 5) Chromium influences the heterogeneity of tracheal element of all the vegetative organs of the test-plants, copper affects the heterogeneity of phloem formations, zinc – the degree of fascicular cambium formation.

- 6) General indexes of small-cellularity of the conformation tissue correlate with the nickel contents in the soil.

Thus, the 6 basic correlation groups are determined, being relatively morpho-physiologically homogenous and showing identical tendencies of reaction of the tissue to the metal pollution.

Comparing indexes for *C. intybus* and *T. perforatum* a certain specific metallogeney is revealed in the blocks of comparison as for characteristics of the multiserial structure of rhizoderm habitual asymmetry of the root, fascicular cambium production and atypically of the stomatal-closing apparatus, that is indicated in the tables 3-8. *C. intybus* revealed itself as more successful for the phytoindication assessment species, as, due to the width of ecological amplitude and high morphoplasticity and metal tolerance indices, the species revealed strong correlation dependencies with the soil pollution level.

Between the correlation coefficient and general overlapping area of zones no significant differences are revealed in the cause of determining the main informative tendencies.

Consequently, in plants, simultaneously with many physiological and biochemical changes under influence of metal pollution [7, 8, 11], significant structural transformations are observed, correlated in the aspect of morphogenetic homogeneity of the tissues and organs into blocks; cover tissues transfer system and others. The indexes in use are informative enough for complex assessing the degree of metal pressure upon the rhizodermosphere. Polymorphism of grassy plants, for example *C. intybus* and *T. perforatum*, has demonstrated an adaptive character. This may be used in testing of a soil contamination by heavy metals.

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СПОЛУЧЕНІСТЬ ПОКАЗНИКІВ СТРУКТУРНОЇ ТРАНСФОРМАЦІЇ РОСЛИН В УМОВАХ МЕТАЛЕВОГО СТРЕСУ

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Висвітлені особливості структурної пластичності рослин техногенних екотопів Донбасу в рамках ризологічного, каулілогічного та фоліологічного аспектів. Визначено 6 загальних сполучених груп, які у морфо-фізіологічному відношенні відносно однорідні та виявляють однакову тенденцію реакції тканин на металеве забруднення. Поліморфізм трав'янистих рослин, на прикладі *Cichorium intybus* L. *Tripleurospermum perforatum* (Merat) M. Lairz має адаптивний характер, що може використовуватися при тестуванні забруднення ґрунтів важкими металами.

Ключові слова: структурна пластичність рослин, металеве забруднення, фітоіндикація.

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