BIOPHYSICAL FRAMEWORK OF SUSTAINABILITY ASSURANCE OF ARABLE CHERNOZEMS UNDER CLIMATE CHANGE CONDITIONS

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Arable chernozems in the region are in a stagnant state of evolutionary crisis caused by agrogenic changes and climate induced changes. As a result, chernozems are vulnerable to various degradative processes. Ensuring sustainability involves the use of adaptive landscape technologies based on supporting complex typogenetic processes.

INTRODUCTION

The current stage of chernozems evolution in the Carpathian-Danubian-Pontic space is characterized by significant reduction of the role of biological factor in the development of basic pedogenic processes, enhancing the role of climate and the biological factor in pedogenesis, the intensification and diversification of direct technical and anthropogenic pressure on the pedogenic processes, but also on the pedogenetic factors. As a result, significant changes and intensity of typogenetic processes and associated chernozems pedogenesis: humus formation process, biogenic accumulation of biophile elements, structuring and carbonate migration.

All this leads to the reduction of soil stability and increased vulnerability to various degradative processes: water and wind erosion, disaggregation and degradation of the structure, especially of the valuable agronomic structure, compacting, salinization, solonization and overwetting.

The specified chernozem processes affecting their trend in the region, which contravenes to unidirectional evolution and reproduction

of their natural fertility. The situation worsens as a result of progressive trends of climate change.

Our research has shown that in the current chernozems evolution in the region these are strongly responsive to climate change, materialized in two opposite contrary effects: desertification and hydromorphism.

The purpose of the present research comprises the development of a biophysical framework to ensure the sustainability of arable chernozems under climate change conditions.

MATERIAL AND METHODS

The concept of soil sustainability is affiliated with the concept soil ecosystem, including soils. According to V. A. Kovda the soil ecosystem is developing as a whole from simple to complex. Within this development ecosystems less stable achieve more advanced stability.

The time sequence of soil ecosystem stability is provided by three factors: 1) Regularizing and self-organizing of the ecosystem development processes, establishment of interactions between components; 2) changing climate conditions; and 3) changing physical environment under the influence and anthropogenic factors.

Stability of the ecosystem is its ability to react proportionally to the magnitude of the impact force. This feature is caused by the ecosystem capacity or its components to oppose the variation of natural factors and preserve its structure and functional particularities (Dragan, 2013).

Sustainable management of ecosystems is a subject less studied. However to achieve this have been outlined four directions: 1) traditional-genetic based on quality indices; 2) regulating pressures on ecosystems with consideration of admissible critical pressures; 3) based on attributes of more receptive ecosystems to external pressures; 4) based on analysis of pedogenic processes by using appropriate nonlinear mathematical models.

Based on examination of all presented directions, we consider that chernozem is more appropriate for the traditional genetic approach based on analysis and the intensity of basic pedogenic processes in the

past and present, which allows prognosis of possible evolutionary processes in the future.

The conceptual and theoretical support of such analysis is assured by the elementary pedogenic processes concept (Gerasimov, 1986) and the concept of anthropized pedogenesis (Jigau, 2009).

This paper is developed on their own research and on the basis of materials systematization from the archive of Republic Center of Applied Pedology obtained under pedologic investigations in the period 2003-2015 to the achievement of which the author participated. Research has been conducted using standardized study methods adjusted to national and international requirements.

RESULTS AND DISCUSSIONS

Soil is a complex system with hierarchical structure (ion-molecular, elementary particle, aggregate, horizon and profile). The soil ecosystem stability is determined by the optimal interaction between these components and the process of formation and humus accumulation at all hierarchical structure-function levels.

Kirjusin V.I. (2000) states, that it is necessary to distinguish natural stability of landscape and agricultural stability of landscape. The driving force of self-regulated operation is the humification process that ensures the interaction between abiotic and biotic factors, materialized in the biorutinary soil system (Jigau, 2009).

In the case of agrolandscapes, soil stability is significantly weakening as a result of reducing the role of the biological factor in soil formation. This leads to the reduction of soil biogenesis materialized in determining priority role of the humus formation process in functioning and extended reproduction of chernozems. Therefore, in the framework of sustainable chernozem management, the emphasis should be placed on restoring and supporting the process of humus formation but not on preserving humus reserves in the soil.

According to our research, the main causes of soil reduction, priority of humus formation process are:

- Perturbation, anthropogenic degradation of pedofunctional framework (pedofunctional regimes) to achieve humus formation process;
- Low energy quality of humus sources, represented by organic residues;
- The deficit of necessary biological nitrogen in order to achieve humus formation process;
- Accelerated intensity within decomposition process of the organic residues (in the absence of humiferous detritus) with the formation of "anthropic" humus less stable;
- Stressful state of soil biota following the "chaotic" dynamics through the composition amount and limits storage of organic waste;
- The considerable reduction of microbiotic biomass to soil from 28-30 to 1-2 t/ha as an active humus renewable source;
- Spatial incoherence of deposition area of organic residues and the optimal conditions in deployment of humus formation processes as a result of intensive degradation of the arable layer;
- The decomposition and biodegradation as a result of humus losses;
- Humus losses due to water and wind erosion.

Reducing the priority role of humus formation process involves a number of quantitative changes in the evolution of organic substance system through the stability reduction of the organic matter system as result of changing the ratio between humiferous detritus and humus.

According to the researchers conducted within the biological station of Moldova State University in the typical chernozems in the areas, not included in the arable circuit humiferous detritus content, consists in 8-12 % of total organic matter content in the 0-5 cm layer. Already in the layer 15-25 cm humiferous detritus content is reduced to 3-5 % from the organic substance content. In the AmB horizon (45-68 cm) the humiferous detritus content is reduced to 1.18 % of the total organic content (Table 1).

In the arable layer of the typical deep humus chernozems, the humiferous detritus is reduced to 2.60-2.98 % of the organic matter

content. In subsequent layers humiferous detritus content increases compared with deep effervescent chernozems without plowing. This allows us to conclude that the crops develop deeper root system. At the same time, arable soils in the AB horizon create less favorable conditions for decomposition of vegetal debris. Even more the plant residues of crop plants harder are decomposed. The same laws are found in case of typical al moderate humifer chernozems but with other expression value.

Table 1

Composition of the organic material in the fallow chernozems and the arable (Codru, Chisinau, MSU Biological station 1990-1994)

Soil	Depth, cm	Content C org, total, %	Content C detritus, % from C tot	Soil	Depth, cm	Content C org, total, %	Content C detritus, % from C tot
Typical	0 – 5	5.81	12.0	Typical al	0 – 5	4.96	2.98
moderate	5 – 15	5.37	6.0	moderate	5 – 15	4.37	1.87
deep humus	15 – 25	4.89	5.1	deep humus	15 – 25	3.58	1.58
chernozems	30 – 40	4.56	3.3	chernozems	30 – 40	2.98	1.98
fallow	45 – 60	3.96	1.18	arable	45 – 60	2.33	1.73
Typical	0 – 5	5.28	8.3	Typical	0 – 5	4.20	2.60
moderate	5 – 15	4.63	5.1	al moder-	5 – 15	3.86	1.83
deep humus	15 – 25	4.21	3.8	ate humus	15 – 25	3.12	1.54
chernozems	30 – 40	3.38	2.6	chernozems	30 – 40	2.67	2.28
fallow	45 – 60	2.86	1.2	arable	45 – 60	2.13	1.96

In the soil a unidirectional trend is established in the sense of reducing the humus content and its compliance with newly created condition by the landscape (Table 2).

Table 2

Dynamics of surfaces with different levels of humus assurance in some pedogeographic districts (% of the district), *

Pedogeographic district, no	Predominant soil	Evaluation period	Degree of humus insurance				
			Very low	Low	Moderate	Optimum	High
1.	Gray soils, argilo-clay chernozems and levigated	1965-1970	0.5	23.3	63.6	10.1	2.5
		1970-1975	1.0	18.7	57.6	17.2	5.4
		1975-1980	1.6	14.1	51.6	24.3	8.4
		1980-1985	1.8	13.3	41.2	35.6	1.1
		1985-1990	-	17.0	37.3	44.7	1.0
2.	Typical al moderate humus chernozems	1965-1970	0.4	15.3	55.7	28.6	-
		1970-1975	1.5	13.4	47.6	40.3	7.2
		1975-1980	2.3	11.5	39.5	43.2	3.2
		1980-1985	1.6	15.8	45.5	34.5	2.6
		1985-1990	1.6	11.0	46.5	38.9	2.0
10.	Typical al moderate humus chernozems and levigated	1965-1970	-	18.8	54.6	26.6	-
		1970-1975	2.6	21.8	50.0	15.6	-
		1975-1980	4.6	24.9	55.4	15.1	-
		1980-1985	10.2	40.2	41.8	4.8	-
		1985-1990	16.9	43.4	36.5	3.2	-
5.	Typical al moderate humus chernozems and levigated	1965-1970	-	19.4	62.7	17.9	-
		1970-1975	8.3	29.1	50.1	12.5	-
		1975-1980	9.4	38.9	43.7	7.1	-
		1980-1985	12.5	44.8	38.1	4.5	-
		1985-1990	13.6	34.9	47.6	3.9	-
9.	Levigated chernozems, argilo-clay and gray soils	1965-1970	-	22.7	55.8	21.5	-
		1970-1975	4.3	28.6	50.3	16.8	-
		1975-1980	9.0	35.0	43.9	12.1	-
		1980-1985	8.5	36.2	45.3	9.8	-
		1985-1990	11.0	43.0	46.7	9.3	-
District II a	Typical low humus chernozems	1965-1970	1.4	18.7	58.5	20.3	0.6
		1970-1975	4.2	19.3	53.2	21.9	1.3
		1975-1980	6.0	19.8	46.0	23.0	5.2
		1980-1985	8.9	35.1	52.0	3.9	0.8
		1985-1990	8.1	30.9	56.5	4,5	-

District 13 b	Carbonated chernozems	1965-1970	5.0	41.5	45.1	6.6	1.8
		1970-1975	20.0	42.0	30.1	6.3	1.6
		1975-1980	22.9	42.9	27.1	5.5	1.8
		1980-1985	18.8	44.0	29.7	5.6	0.9
		1985-1990	19.4	51.5	28.0	1.0	-

* from the archive of Republic Center of Applied Pedology

Quantitative expression of its trend varies in time and space in accordance with pedogeographic conditions and concrete landscape conditions (Table 3).

Table 3

State and dynamics of humus content in agrolandscape in Moldova in the period 1965-2013 in per cent *

Agri-cultural unit	No. Field	Predominant soil	Evaluation period					
			1965-1970	1970-1975	1975-1980	1980-1985	1985-1990	2003-2013
Agros-fera BM Nisporeni	1	Typical al chernozems silty clay	4.9	4.5	4.5	4.2	4.1	4.1
	2	Typical al chernozems silty clay	5.1	4.7	4.6	4.4	4.1	4.1
	3	Typical al chernozems with solonetz area	4.9	4.6	4.3	4.3	4.3	4.0
	4	Typical al chernozems with eroded areas	3.8	3.4	3.0	3.1	3.0	2.9
	5	Typical al chernozems with eroded areas	4.1	3.8	3.5	3.2	3.0	2.9

Vindex agro Orhei	1	Typical al chernozems silty clay	5.3	4.9	4.6	4.3	4.2	4.0
	2	Typical al chernozems loamy	5.1	4.7	4.6	4.4	4.2	4.0
	3	Typical al chernozems loamy	4.9	4.6	4.3	4.6	4.3	4.0
Podg-oreni, Cantemir	1	Typical al low humus chernozems, low-moder-ate eroded	3.6	3.3	2.9	3.1	3.0	2.9
	2	Typical al low humus chernozems, low eroded	3.9	3.6	3.4	3.1	3.0	3.0
	3	Typical al low humus chernozems, moderate eroded	2.8	2.4	2.1	2.0	1.9	1.9
	4	Typical al low humus chernozems, low-moder-ate eroded	3.7	3.4	3.1	3.1	3.0	2.9

Mevil-Agro, Ocnița	1	Typical al chernozems silty clay	5.7	5.3	5.1	4.7	4.5	4.4
	2	Typical al levigated chernozems silty clay	5.9	5.5	5.2	5.0	5.0	4.7
	3	Typical al chernozems silty clay, low-moderate eroded	5.5	4.6	4.3	4.2	3.9	3.8

* from the archive of Republic Center of Applied Pedology

The data presented in the table 2 and 3 highlight the fact that the intensive humus content in the chernozems, in the region, is reduced in the first 15-20 years after the intensive agricultural circuit (about 50-60 of humus losses return to this period). During this period, humus reserves are reduced as a result of mass mineralization of the humus detritus driven to disturbance of climate bioenergetic state of chernozems in the region. Later (around 10-15 years) humus reserves are reduced more slowly as a result of reduction in the content of humic labile substances determined by decrease in content of fresh energy sources in the soil, disturbing the dynamics of formation process and accumulation of humus, worsening composition and quality of organic residues. Reducing humus reserves at this stage leads to the initiation of soil mass disintegration processes, which affected the reproduction process of the clod and the grainy structure; in particular of aggregate with a diameter of 3-1 mm, with an increase in aggregate content 1.0-0.25 mm. This led to intensification of both water erosion and wind.

During 40-45 years the chernozems in the region under conditions with relief elements < 2° in the agricultural regime comparative with humus reserves in the fallow soils were reduced by 20-30 %. In case of cereal crops humus losses make up 20-25 % and in the hoeing and technical 25-30 %.

In the erosion slopes humus losses reach up 30-40 %. The first generalization of evolutionary laws of the organic matter system to the chernozems in the region shows that the components of the agricultural system differently influence the organic substances system (Jigau, 2016):

- Crop structure and duration of their rotation influences the humus detritus content;
- The fertilization system influences the content and composition fraction of labile humus; for the bioclimatic conditions in the Prut-Nistru space optimal values of ratio C: N = 10 – 12:1. Lower values indicate unproductive losses of nitrogen; higher values denote nitrogen deficiency to carry out humification processes;
- Tillage systems influence the content and composition of humus detritus and labile humus substances.

According to calculations by Masyutenko N. P. (2008) within existing agricultural system under traditional crop rotation over 100 years, humus reserves in the chernozems will be reduced by 26 %, over 200 by 42 % and over 500 with 62 %.

In the ameliorative crops rotation the evolution of humus means reducing humus reserves over 100 years with 12 %, over 200 years with 20 %, over 500 years with 29 %. In the context of the exposed ones the bioenergetic state of the chernozems in the region can be evaluated by the parameters presented in the table 4.

Table 4

The bioenergetic parameters of the chernozems of the Prut – Nistru space

Fertility factors	**Normative for fertility levels**		
	low	**Moderate**	**High**
Humus content in the horizon Am, %	< 4	4-6	> 6
Layer thickness to achieve the process of humus formation (Am+AmB), cm	< 50	50-65	> 65

The thickness of humus layer (A+B), cm	< 60	60-80	> 80
Humus reserves, T/ha layer 0-100 cm	< 350	350-500	>500
Ratio C:N in composition of humus	>13:1	10-13:1	≤ 10:1
Ratio Cah:Caf	< 1.4	1.4-2.0	> 2.0
The content of mobile humus substances, mgC/100 g of soil	100-200	200-300	300-400
Variation intervals of the content of labile humus substances, mgC/100g of soil	90-170	170-271	271-393
Limit values for accumulation of humus, %	4.0-4.5	6.5-7.0	8.0-8.5
The content of organic substances easily decomposed into the arable layer, % soil mass	0,35-0.55	0.55-0.8	0.8-1.2

In the context of parameters presented in the table 4 their lower limits represent the value below which crops are significantly reduced and the reproductive capacity of soil ecosystem resources. Maximum values (upper limit) are the economically and ecologically justified values of reproductive activities for bioenergetic parameters.

The assessment of bioenergetic parameters of chernozems in the region implies the use of two indicators: critical humus content and state allowable limit.

Critic content represent the amount of humus below which physical features (agronomic and environmental) can still be reproduced. This is 4.0 %. Allowable limit of humus content (≈3 %) under which a number of physical parameters (apparent density, structural-aggregate state, parameters of the porous space, hydro-physical parameters) show values that are characteristic of parental substrates (parental rocks).

In conditions when the humus content falls below the critical level in the soil evolution occurs super-cultivation state, accompanied by destructive elemental process, destructuring and intensive compact-

ing due to intensive use under low flux condition of energy sources (humus sources). In case when humus content in soil falls below the allowable limits starts desertification processes in soils. In this context applying humus content and its inherent bioenergy parameters as an evolutionary indicator of chernozems, we find that the contemporary process of humus formation maintains the biogeosystem in the region in a state of energetic stagnation and retain the ability to respond to energy inputs.

This implies the conclusion that to ensure the sustainability of materialized chernozems in the extended reproduction of their bioproductive function is necessary to restore the priority role of the humus formation process in the context of adaptive-landscape-ameliorative technologies, based on the efficient combination of biological and technological methods which support the typogenetic processes of chernozems formation by using sources of organic matter added to the soil, implementation of ameliorative crops and conservative rotational system of soils, the use of bio and pedo- rotated fertilization system, supporting biochemical processes in soils by applying biohumic preparations.

In the sustainable management of chernozems emphasis has to be placed on management and control of substance transformation processes and interactions between them in the pedogenic process by practicing biofertilizers. These are preparations which are administered in soils in smaller amount that manure as catalysts which influence the processes of decomposition-transformation of organic and mineral substances and targeted to support the functioning process in soil microbiocenoses efficiency, the humus formation process and the organic-mineral reactions responsible for the structural-functional soil organization.

The technologies developed in the Scientific Research Laboratory Pedogenetic Process of MSU in collaboration with SRL "AXEDUM", emphasis is placed on the use of Biohumus and Biovit bioorganic preparation. The latter represents the fraction of the labile humic substances resulting from technological process for obtaining Biohumus. Except compost Biohumus and Biovit represents the biologic active substances (Table 5 and Figure 1).

Table 5

The content of macro and microelements in Biohumus

Indices	Unit of measure	Values indices	
		In the natural	In the dry
pH	%	7.8	
Ash content		69.7	46.6
Organic substance content		30.3	53.4
Total nitrogen content		0.88	1.55
Ammoniac nitrogen content		abs	abs
P_2O_5 content		0.97	1.70
K_2O content		1.05	1.85
$N\text{-}NO_3$ content	mg/100g	608.7	1071.6
Calcium content	moli/100g	19.0	
Magnesium content		22.0	
Mobile copper content	mg/kg	1.16	2.05
Mobile zinc content		4.30	7.60
Mobile manganese content		5.30	9.30
Mobile iron content		3.00	5.30
Colonies of microorganism/1g		20000 billions	

In the Biovit's composition about 67-84 % from the total biomass return to the active microbial biomass. The catalytic potential of Biohumus and Biovit is achieved only in the presence of fresh organic matter. It is better to use them in installments. In this respect, research has shown that the use of biohumic preparation in installments ensures that organisms that decompose humus are reduced 2-3 times (13 versus 39-44 %) compared to administration of the same amount of biochemical preparation in a single rate. At the same time, their administration leads to intensification to a series of pedogenetic processes:

- Formation and accumulation of humus;
- Micro and macro-structuring of soils;
- Intense decomposition processes of organic residues and nitrification (Figure 1).

CONCLUSIONS

The pedogenesis regimes induced in chernozems by agrogenic changes and climatic conditions in phase change have reduced the priority role of the humus formation process in the evolution of the chernozems in the space between Prut and Nistru. This severely affects the structuring process and the extent of pedogenesis on the descendant with the concentration on the elementary processes in the agrogenic layer. Therefore, the chernozems in the region are in a stagnant evolutionary phase being extremely vulnerable to various degradative processes. Ensuring the chernozems sustainability can be achieved within a complex technology based on typogenetic processes: humus formation and accumulation, biogenic accumulation, structuring and migration of carbonates.

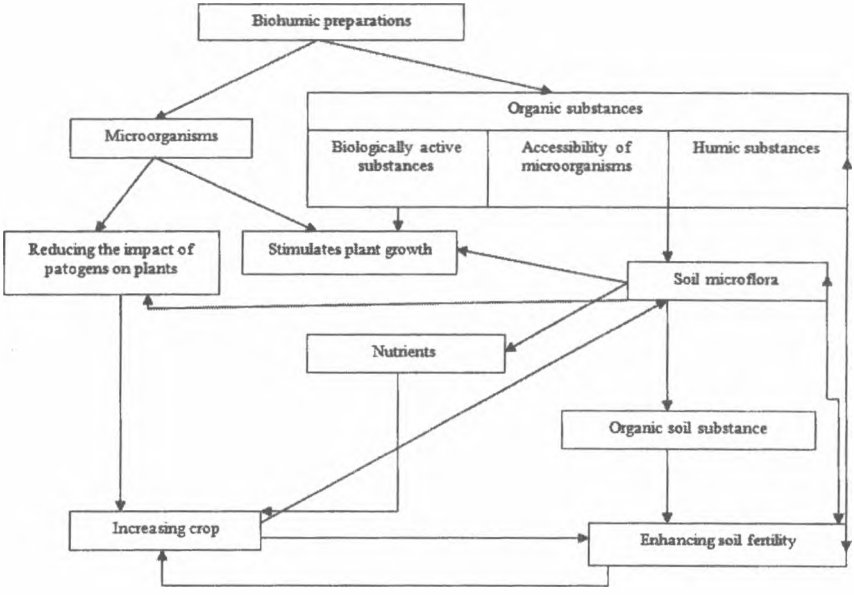


Figure 1. Mechanisms of polyfunctional action of biohumic preparation on soil-plant relations

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