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CURRENT HUMUS STATE OF SOILS IN CONDITIONS OF INTENSIVE DEGRADATION PROCESSES IN MOLDOVA

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The paper contains the research results on the evolution of humus content in the arable soils of the Republic of Moldova during 1961–2010. The current humus state of arable soils caused of the agricultural long period of utilization. Studies carried out in Moldova, more than 140 years ago, found that chernozem contained about 5–6 % of humus. In subsequent years, the natural fertility of the soil of Moldova has been declining. In the present the humus content reached the level of 3.1 % on average for the whole agricultural area. As a result of over 140 years from the original natural soil fertility remains 50–60 %. In the recent years the average doses of applied fertilizers on the Moldovan soils were 25 kg/ha. During the last years, the state programs for remediation of humus content, the chemical, physical and biological soil properties, concerning the soil and water protection by the nutrient pollution and substances of plant protection products have been developed.

Key words: humus loss, soil degradation, chernozem, fertilizer, measures.

According to the Statistical Yearbook of Moldova, on January 1, 2012 the total area of lands was 3.38 million ha, including the agricultural lands – 2.50 million ha (73.8 %), forest lands – 463.1 thousand ha (13.7 %). Of the total area of agricultural lands (farmlands) of 2.50 million ha, the arable lands constitute 1.81 million ha (72.6 %), orchards occupy 133.3 thousands ha (5.3 %), vineyards – 149.6 thousands ha (6.0 %) and pastures – 350.4 thousands ha (14.0 %). The presented data shows that the share of farmlands is inadmissible large (73.8 %) and for forest is 2–3 times less than optimal ones. The unbalance between natural and anthro-pogenic ecosystems causes the amplification of the various forms of land degradation in Moldova [1]. The soil structure is quite complex. The main soil types and subtypes are: chernozems (black earth), occupying 70 %; brown and gray soils – 10.2 %; alluvial soils – 10.2 % and deluvial soils – 4,0 % [2, 3]. At present, according to the Land Cadastre of the Republic of Moldova on 01.01.2012 the soil note of creditworthiness is 63 points [4].

Humus is one of the main indices of the soil fertility. This fundamental component of soils determines a great extent its chemical, physical and biological properties. The preservation of crops and biota with the mineral nutrition depends directly on the organic matter in the soil.

The current humus state of arable soils caused of the agricultural long period of utiliza-tion. Studies carried out in Moldova, more than 140 years ago, by soil scientist V. Dokuchaev found that black soil (chernozem) contained 5–6 % of humus. In subsequent years, the natural fertility of the soil of Moldova has been declining. The rhythms of these processes are different depending on the nature of the use of agricultural land. The mean value of the loss of soil organic matter was 0.51 t ha^{-1} per year [3, 5].

Since the 1953 the research institutions and universities have been carried out the agrochemical monitoring. At the same time the balance of humus in the soils has been calculated. It was established that before the period of the intensive chimization (1965–1990) the humus balance was negative. Agrochemical Service found that over the period 1986–1990 the humus content reached the level of 3.1 % on average for the whole agricultural area. As a result of over 140 years from the original natural soil fertility remains 50–60 % [6, 7].

The present period is very important and can be called critical, referring to the state of soil humus. If the degradation of the natural fertility will not be stopped by adequate measures, the level of humus reaches a value close to 2 %, which corresponds to the lower threshold for black soil. Humus stabilization at this level will limit grain yields of 1.5–2.0 t ha^{-1}. Regeneration of soil fertility, from a critical level, it will be very difficult to implement, required the cost and effort will be much larger and longer.

Humus loss of agricultural land associated with many factors, among which the most important are practiced crop rotation, tillage, return the amount of organic matter with organic fertilizers, etc. The bases of the humus stability of soils used in agriculture are crop rotation and succession cropping. Crop rotation should return most of the mineralized soil humus. The use of organic fertilizers and other factors favorable to the accumulation of humus in the soil ensures the preservation and improvement of soil fertility [6]. From this point of view, the data shown in table 1, indicate the content of accumulated humus, loss and balance in dependence of the cultivated crops.

Table 1

The balance of humus in the soil for agricultural crops (average data 1990–2010)

Crop	**Accumulated humus**		**Humus loss**		**Humus balance**	
	thousand tons	t ha^{-1}	thousand tons	t ha^{-1}	thousand tons	t ha^{-1}
Winter wheat	285	0.90	401	1.06	-116	-0.16
Winter barley	62	0.68	69	1.09	-7	-0.41
Spring barley	26	0.60	47	1.06	-21	-0.46
Oats	2	0.49	33	0.85	-31	-0.36
Corn for grain	251	0.74	520	1.56	-269	-0.82
Sunflower	55	0.38	171	1.20	-116	-0.82
Sugar beet	47	0.69	157	2.00	-110	-1.31
Tobacco	22	0.88	178	0.72	-156	-0.68
Vegetables	12	0.22	26	0.57	-14	-0.32
Peas	18	0.46	24	0.60	-6	-0.14
Beans	6	0.29	7	0.37	-1	-0.08
Soybean	4	0.32	5	0.84	-1	-0.52
Corn for silage	53	0.32	140	0.87	-87	-0.55
Perennial grasses	44	0.85	24	0.62	+20	+0.23
Average	***63***	***0.50***	***129***	***1.00***	***-66***	***-0.5***

The biggest losses of humus are characteristic for clean-tilled crops. Loss of humus in growing corn varies widely, depending on the year and occupied areas. On average, for 20 years, the humus losses amount to 520 thousand tons or 1.56 t ha^{-1}. Loss of humus per hectare occupied by sugar beet was 2 t ha^{-1} in average for 20 years. Sunflower growing in this respect is intermediate between maize grain and sugar beets crops. The share of clean-tilled crops increased in recent years and came close to 65 % of the total area of arable land.

Close-growing (densely cover) crops are more favorable in terms of soil humus loss. During the growth of the winter wheat, spring and winter barley, the mineralization of humus is slightly higher than the level of 1 t ha^{-1} on average for 20 years and the oats growing is below of this threshold.

To create a good basis for restoration of the soil fertility is very important the technology of perennial grasses cultivation that helps enrich their organic matter. Perennial grasses, occupied in 1990 the area of 100 hectares, now their share is negligible. Due to this fact, the arable soils annually lost the large amounts of humus, difficult to recoverable by applying of organic fertilizers and other sources of organic material of local origin. If the annual losses of organic matter caused by mineralization, add losses from water erosion which reach 606 thousand tons or 0.43 t ha^{-1}, each hectare of arable land is eliminated annually 1.43 tons of humus.

Information regarding income of humus with crop residues and manure takes into account the deductible loss, after which the estimated resources needed to compensate them. Root crops that best promotes the decomposition of humus in the soil have low values of his compensation, which remained on the land surface. Maize and sugar beet return into the soil only 700 kg of humus from plant residues, that 2–3 times less than its consumption. Cereals crops characterized similarly income of humus, but it consumes much less, as has been noted.

A special place with regard to the accumulation of organic matter in the soils belongs to the perennial grasses, mainly present in the agriculture of Moldova, is alfalfa (*Lucerne*). Its share in the accumulation of humus in the soils is 0.85 t ha^{-1}.

Another very important source of accumulation of organic matter in the soil is the local organic fertilizers. Under the conditions of a balanced crop rotation, in terms of regeneration of soil fertility, they own a compensatory role in deficiency of humus. In 1990, due to organic fertilizers in arable soils formed 417 thousand tons of humus, which is more than 25 % of the total. Currently, the quantity of organic fertilizers use in agriculture decreased to the difficult accounted values – 20 kg ha^{-1}. This important source of soil humus regeneration, because that is not used for other purposes was a major factor of environmental pollution.

Average for 20 years relating to the humus in arable soils formed from crop residues and manure shows that practiced farming aims to unilateral use of soil fertility in the absence of measures to encourage conservation. Annual loss, on average, equal to 1 000 kg of humus per hectare compensated for crop residues at the level of 50 %. As a consequence, the rate of agricultural land dehumification is 500 kg of humus per year, excluding losses caused by water erosion.

Humus balance The data of table 1 show the role of agricultural crops in maintaining the soil fertility. In growing cereals crops the negative humus balance varies, from 0.16 t ha^{-1} of winter wheat to 0.46 t ha^{-1} of spring barley. The largest negative values of humus balance were reported in clean-tilled crops. Rate of soil organic matter loss under maize and sunflower is 0.82 t ha^{-1}.

Sugar beet is characterized by maximum values uncompensated humus losses of 1.31 t ha^{-1}. The vegetables in terms of loss of soil organic matter similar to cereals. In growing of peas and beans is set a slightly negative humus balance between 0.14–0.08 t ha^{-1}. The negative balance of humus is characteristic for all agricultural crops except for perennial grasses. Average data for 20 years on the accumulation and decomposition of soil organic matter in growing perennials grasses demonstrates their special role in maintaining of soil fertility.

From plant residues, as ground and underground, annually are synthesized about 44 tons of humus, while his loss of biodegradation were 24 thousand tonnes. Thus, in the soil were accumulate an average of 20 tons of humus or 0.23 t ha^{-1}. In agriculture of Moldova the perennial grasses should be a major factor in maintaining and improving the soil fertility.

The current situation, characterized by a maximum loss of soil organic matter and minimum compensation with crop residues required largely to the fact that the period, beginning in 1999, the area of alfalfa and other perennial grasses declined sharply, while a significant increase in the proportion of clean-tilled crops. By the quantity of accumulated humus in the soil, in the period 1990–1992 year is very different. Humus balance was slightly negative and very close to balanced.

In 1990, uncompensated losses of humus were minimal and accounted 87 tonnes in the arable soils. Per unit of area the humus loss did not exceed 60 kg ha^{-1}. This situation lasted another 2 years (1991–1992). Then it has changed quite dramatically. Beginning in 1993 and until 2002 in arable soils establish a deep negative balance of humus. Annual loss in this period varied between 0.43–0.83 t ha^{-1}. Current status of soil fertility is determined by 1997–2002 period.

Humus balance in arable soils from negative in the early 90's now is established at the lowest level, with annual losses uncompensated 0.74 t ha^{-1}. This state of humus also characteristic for the following years 2000–2003, due the changes in the flow of carbon has not occurred. The general information of humus status evolution in arable soils is presented in table 2.

Table 2

The evolution of the humus balance in arable soils, t ha^{-1}

Years	**Organic fertilizers applied, t/ha**	**Balance of humus**	
		without erosion losses	with erosion losses
1971–1975	2.9	0.5	-0.9
1976–1980	3.9	0.4	-0.8
1981–1985	6.0	0.1	-0.5
1986–1990	5.6	0.1	-0.5
1991–1995	2.6	0.4	-0.8
1996–2000	0.1	0.7	-1.1
2001–2005	0.1	0.7	-1.1
2006–2010	0.01	0.7	-1.1

Over the last 10–15 years the insufficient quantities of manure (0.01–0.60 t ha^{-1}) has been incorporated into the soil. The balance of organic matter is negative, minus 0.7 t ha^{-1}, while with the losses by erosion is -1.1 t ha^{-1}.

Evolution of humus balance for 40 years (1971–2010) shows the negative balance. However, negative values were different depending on the crop rotation and the amount of organic matter is returned to soil by local organically fertilizers.

For the 1971–1975 years, the soil lost every year 0.5 t ha^{-1} of humus. For 90 years marked a gradual improvement in the balance of humus, while increasing doses of organic fertilizers applied to the soil. The systematic applied of fertilizers, including 5–7 t ha^{-1} of manure, the cultivation of perennial grasses on about 10 % of the arable land (180–210 thousand ha) contributed to the formation during the 1975–1980 years to a slightly deficient balance of humus in soils, minus 0.1 t ha^{-1}.

In the 1981–1990 period, uncompensated loss of humus characterized minimum values equal to 0.1 t ha^{-1} per year. After 1991 had already begun these negative processes by which currently have the worst situation in the humus of soils developed over the last 30–40 years.

Annual losses of humus in arable soils, if we take into account those that are caused by water erosion exceed the average level of -1.1 t ha^{-1} per year. Repeating the above, note the following:

- Humus state of arable soils is the most unfavorable for the last 30–40 years;
- Annual, uncompensated loss of humus in agricultural lands due to its mineral content, higher than the level of 0.7 t ha^{-1} per year, but total deficit, given the erosion processes are -1.1 tons per year;
- The main factors that contributed to the establishment of a deep negative balance of soil organic matter is the lack of crop rotation, focused on soil conservation, water erosion, and the use of very small amounts of local organic fertilizers applied to agricultural crops.

Urgent measures to improve the humus status of arable soils are:

- Minimizing soil loss due to water erosion;
- Optimization of crop rotation by reducing the proportion of clean-tilled crop and a significant increase of annual grasses area and perennial grasses in particular;
- Minimizing tillage to inhibition of decomposition of humus in the soil;
- Extensive use of all available resources of the local organic material to fertilize the soil (waste of livestock sector, communal services, food processors of agricultural raw materials, and other organogenic origin waste, suitable for the preparation of organic fertilizers);

Nitrification capacity According to the Agrochemical Research Service approximately 39 % of farmlands are characterized with a low content of organic matter (less than 2 %), 40 % with moderate (2–4 % of humus) and only 20 % with the humus content higher than 3 % [7,9].

As a result, about 80 % of soils are characterized by a very low and low nitrification capacity. On agricultural lands with the humus content of less than 2 % by the nitrification processes in the soil only 50–60 kg ha^{-1} of nitrogen is accumulated and the soils with 3.0–4.5 % of organic matter – up to 75–110 kg ha^{-1} of the mineral nitrogen. These quantities of the mineral nitrogen are sufficient for the formation of 1.7–2.0 t ha^{-1} and 2.5–3.7 t ha^{-1} respectively of the winter wheat.

At present the average content of organic matter in the soils of Moldova is about 3 %. As a result of the mineralization of organic matter, the soils produce annually about 70 kg ha^{-1} of nitrogen. This quantity of nitrogen is sufficient for the formation of 2.4 t ha^{-1} of the winter wheat harvest [8].

Phosphorus has a special role in the metabolism of plants and formation of the elevated harvest. Chernozems as well as the gray soils are characterized by the low content of phosphorus in soil [10, 11]. The intensity of phosphate regime has been confirmed by the research results carried out by the State Agrochemical Service. In the 1971–1975 years the surface of soils with low phosphorus content was quite large and constituted approximately 68 % [7].

In the period of 1965–1990 period about 960 kg/ha of phosphorus was incorporated into the soils. This agrochemical measure influences beneficially on the phosphorus regime of soils. To the 1990 year the surface of soils with low phosphorus content decreased by 2 times, while that with a high phosphorus content increased by 3 times. On average per republic the mobile phosphorus content in the soil increased by 2 times, as a result the productivity of crops plants has been increased [8, 11].

In the recent years (2000–2012) in Moldova's agriculture the insufficient quantities of P_2O_5 (up to 1 kg ha^{-1}) were applied. The export of phosphorus with the harvest is high and constitutes annually about 25–30 kg ha^{-1}. The balance of this nutrient element is negative. Currently the post action with phosphorus fertilizers is practically exhausted. With the natural low background of the mobile phosphorus in soil it is possible to get about 2.5 t ha^{-1} of the winter wheat. This harvest level, usually, has been obtained within the country in recent years.

Potassium The crops for the high harvest formation extract from the soil significant quantities of potassium – 100–200 kg ha^{-1}. The soils of Moldova are rich in the total potassium. But the main reserve of available potassium for plants constitutes the exchangeable form. It was found experimentally that the potassium content for 15–20 mg $100g^{-1}$ of soil is sufficient for the optimal growth and development of crops [8, 10]. According to data only 13 % of the farmlands are characterized with a moderate content (10–20 mg) of exchangeable potassium; 87–95 % of the total area – with a high content.

The systematic use of fertilizers in the 1965–2010 years provided an equilibrated balance of potassium in soil. Therefore, the quantity of exchangeable potassium increased average by 2 mg 100 g^{-1} of soil. Currently, the potassium and organic fertilizers are applied in very small doses. The balance of the K_2O in soil is negative [10]. The soils of Moldova are rich in accessible potassium to plants, but these reserves in a quite long period (150–200 years) may be exhausted. Hence, it is necessary to maintain an optimal regime of potassium already present in the soil by applying fertilizers.

In the conditions of Moldova the natural factors which limit the production of high harvests are the insufficiency of nutrients in the soils as well the moisture deficit. In order to achieve the growth rate in harvest of 40–50 % it is necessary to compensate the deficit of nutrients by the use of fertilizers and rational utilization of the soil moisture.

The optimal application of fertilizers is required a level of the modern agriculture soil no-till with respecting zonal crop rotations, the integrated protection of plants, extension of irrigation, development of the livestock sector, implementation of intensive technologies of plant cultivation. This system is based on the combined application of organic and mineral fertilizers in couple with fuller use of the biologic nitrogen.

The norms of fertilizer vary depending on the crop from 50 kg ha^{-1} NPK for peas up to 225 kg ha^{-1} NPK for sugar beets (tab. 3). According to the Programme [6] the average annual dose of fertilizers on the crop rotation of the agropedoclimatic zones constitutes:

- North – 5 t ha^{-1} manure and $N_{61}P_{50}K_{20}$;
- Center – 4 t h^{-1} manure and $N_{54}P_{45}K_{18}$;
- South – 4 t ha^{-1} manure and $N_{47}P_{43}K_{18}$.

The implementation of the crop rotation with the optimum share of leguminous will allow the accumulation in soil of 30–35 kg ha^{-1} per year by the biological nitrogen fixation. The systematic application of fertilizers and organic minerals in doses of P_{55-60} will allow forming into a multiannual cycle a positive balance and an optimal level of phosphorus in the soil for obtaining high harvests.

The average dosage of K_{19} fertilizers will be insufficient for the stabilization of potassium in soil. The compensation of the potassium loss will be covered by the local fertilizers and the application of the secondary production as organic fertilizer. The nitrogen deficit will be compensated by the biologic nitrogen (30–35 kg ha^{-1}), manure (25–30 kg ha^{-1}) and mineral fertilizers (50–60 kg ha^{-1}). The share of nitrogen from mineral fertilizers will constitute about 50 % of the total content.

Table 3

The optimum doses of mineral fertilizers for the fertilization of the main crops plants, kg/ha of the active substance

Crop plants	Recommended dose			Remark
	N	P_2O_5	K_2O	
Winter wheat	80	60	40	annual
Winter barley	34	60	0	*
Spring barley	34	60	0	*
Maize for grains	60	50	0	*
Sugar beet	105	80	40	*
Sunflower	45	40	40	*
Tobacco	35	40	40	*
Potatoes	60	60	60	*
Vegetables	90	60	60	*
Maize for silage	40	40	0	*
Fruitful vineyards	60	60	60	once in 3 years
Fruitful orchards	60	60	60	once in 3 years
New vineyards (founding)	-	400	400	to the founding
New orchards (founding)	-	400	400	to the founding

The optimal demand for nitrogenous fertilizers for the crop rotation will be 82.3 thousand tons of the active substance or N_{55} on average per 1 ha (tab. 4).

The total annual demand of fertilizers for the agriculture of the Republic of Moldova after 2020 will constitute 236.7 thousand tons of the active substance, including 99.9 tons of nitrogen, 91.0 thousand tons of phosphorus and 45.8 thousand tons of potassium. This level of fertilization was reached in the 1976–1985 years by applying annually 243.6–362.0 thousand tons.

Table 4

The annual mineral fertilizer requirements for the optimal crop fertilization, thousand tons of the active substance

Branch, crop plants	Nitrogen, N	Phosphorus, P_2O_5	Potassium, K_2O
Crop rotation	82.3	69.9	28.4
Vegetables and potatoes	6.8	9.0	6.8
Fruitful vineyards	1.5	1.5	1.5
Fruitful orchards	2.0	2.0	2.0
New vineyards	0	2.1	2.1
New orchards	0	1.0	1.0
In addition to irrigated lands	6.3	4.6	3.1
Other crop plants	1.0	1.0	1.0
Total for Moldova	***99.9***	***91.1***	***45.9***

The use of the optimal fertilization system coupled with other technological links of cultivation of the crop plants will allow to get 4.0–4.2 tons of the winter wheat, 3.6 tons of grain maize and will form an equilibrated nutrient balance in Moldova's agriculture.

To conservation and enhancement the soil fertility were developed a complex of phytotechnical, agrotechnical and agrochemical measures, which include [6, 12]:

- Optimization of crop rotation and their implementation in each pedoclimatic zone of Moldova;
- Increasing the quota of perennial grasses (alfalfa, sainfoin) in field cropping up to 10–12 %;
- Increasing the quota of annual legume crops (peas, beans, and soya) in field cropping up to 10–20 %. These changes in the structure of the crop rotation will allow accumulating annually about 40–50 thousand tons of nitrogen or 30–35 kg ha^{-1};
- Annual incorporation into the soil 5–6 t ha^{-1} of manure; total of 9–10 million tons;
- Application of 100 thousand tons of nitrogen and 90 thousand tons of phosphorus; total of 190 thousand tons;
- Minimizing the admissible limits of about 5 t ha^{-1} of soil erosion.

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СУЧАСНИЙ СТАН ГУМУСУ ҐРУНТІВ В УМОВАХ ІНТЕНСИФІКАЦІЇ ПРОЦЕСІВ ДЕГРАДАЦІЇ У МОЛДОВІ

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Наведено результати досліджень з еволюції вмісту гумусу в ґрунтах орних угідь Республіки Молдова в 1961–2010 рр. Сучасний стан гумусу орних ґрунтів зумовлений тривалим періодом сільськогосподарського використання. Дослідження, проведені в Молдові більше 140 років тому, засвідчили, що в чорноземі міститься близько 5–6 % гумусу. У наступні роки природна родючість ґрунтів Молдови знижувалася. Сьогодні вміст гумусу досяг рівня 3,1 % в середньому за весь сільськогосподарський період. Протягом 140 років від первісної природної родючості ґрунту залишилося 50–60 %. В останні роки середні дози внесених добрив в ґрунтах становлять 25 кг/га. Розроблено державні програми з відновлення родючості, хімічних, фізичних та біологічних властивостей ґрунтів, а також захисту ґрунтів і вод від забруднення біогенними речовинами і засобів захисту рослин.

Ключові слова: втрати гумусу, деградація ґрунтів, чорнозем, добрива, заходи.

СОВРЕМЕННОЕ СОСТОЯНИЕ ГУМУСА ПОЧВ В УСЛОВИЯХ ИНТЕНСИФИКАЦИИ ПРОЦЕССОВ ДЕГРАДАЦИИ В МОЛДОВЕ

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Работа содержит результаты исследований по эволюции содержания гумуса в почвах пахотных угодий Республики Молдова в 1961–2010. Сегодня состояние гумуса пахотных почв вызвано длительным периодом сельскохозяйственного использования. Исследования, проведенные в Молдове более 140 лет назад, показали, что в черноземе содержится около 5–6 % гумуса. В последующие годы естественное плодородие почв Молдовы снижалось. В настоящее время содержание гумуса достигло уровня 3,1 % в среднем за весь сельскохозяйственный период. В течение 140 лет от первоначального естественного плодородия почвы осталось 50–60 %. В последние годы средние дозы вносимых удобрений в почвах составляют 25 кг/га. Разработано государственные программы по восстановлению плодородия, химических, физических и биологических свойств почв, а также защиты почв и вод от загрязнения биогенными веществами и средств защиты растений.

Ключевые слова: потери гумуса, деградация почв, чернозем, удобрения, мероприятия.