SOURCES AND FORMS OF SOIL CHEMICAL DEGRADATION

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Abstract. The main sources of soil pollution, the types and the forms of chernozem degradation are presented in the present article. It was established that in a period of 100 years, as a result of the mineralization processes, 40–47% of the initial humus reserves were lost, which constitutes 0.5–0.6 t/ha or 0.013–0.018% annually. In the course of 105 years, 3.4 t/ha of N, 0.9 tons of P_2O_5 and 6.8 t/ha of K_2O were extracted and exported with the harvest from the soils of the Republic of Moldova. The chemical degradation of the soils led to the intensification of the physical and biological degradation processes, and as consequence the production capacity of the agricultural fields decreased. In order to stabilize or to increase the humus contents in the chernozems, it is necessary to minimize the soil erosion to the admissible limits, to observe the scientifically proven crop rotation system with the quota of perennial grasses of 10–15% and to incorporate an average of 10 t/ha manure and 150–180 kg/ha of NPK per crop rotation annually.

Keywords: chernozem, humus degradation, soil degradation, soil nutritive elements.

1. Introduction

The soils constitute the main and, in fact, the only natural wealth of the Republic of Moldova. The efficient usage of this natural gift conditions, to a great extent, the economic development of the country and the population’s well-being. The fertile soils and the favorable thermal regime make possible the cultivation of a large spectrum of important agricultural crops such as: vines, oil plants, vege tables, fruits (including nuts and plums), sun-flower, etc.

The Republic of Moldova is characterized by a very complex soil cover. The variability and the zone areas of the soils are determined by the peculiarities of the climate, relief, the geomorphic construction, and the vegetation. The chernozem predominate in the structure of soil covers; their quota constitutes about 70%. The brown and grey soils, formed under forest vegetation, occupy 10% of the land

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fund surface. An important group of soils, as being used in agriculture and forming an ecological niche for biodiversity conservation, is that of alluvial soils including the hydromorphic ones (8.4% or about 300,000 hectares).

The uneven geomorphologic structure, the sedimentary geological rocks, the hilly relief as well as other natural and anthropoid factors very often favour the soil degradation processes [1].

The average solvability mark of the soils from the Republic of Moldova constitutes 64 points as of 12.01.2008. The natural soil fertility secures the yield of 2.5 t/ha of autumn wheat.

According to the Land Cadastre of the Republic of Moldova [2], on January 2008, the total surface of terrains constituted 3.38 million hectares, including 2.51 million ha (75%) of agricultural lands out of which 1.82 million hectares are arable lands (73%), about 12% are orchards and vine yards, and about 14% are pastures. The forest fund is quite small and constitutes about 12%.

Based on the submitted data, the quota of agricultural fields is inadmissibly large (75%), while that of the forest fund is by two to three times smaller than the optimal one. The ecologic lack of balance between the natural and anthropoid ecosystems determine the promotion and intensification of various types and forms of soil degradation [3–6], including the chernozems used in agricultural purposes [7]. In the present article, we include the experimental data obtained in the course of the last 130 years in the process of studying the chernozems from the point of view of their chemical degradation.

The main sources of soil pollution are: residual household and industrial waters, chemicals used for plant protection, irrigation water that contains an increased degree of mineralization, oil products, exhaust gases, industrial wastes, and organic wastes from animal farms.

Chernozem degradation is grouped into five types and 40 forms [7]. The chemical degradation is of 10 forms, including dehumification, soil wearing out of nutritive elements (N, P, K, Ca), insufficiency and/or surplus of microelements, surplus of salts in the soil, and radio nuclide pollution.

This paper will refer to the most widely spread forms of chemical degradation of chernozems and namely: mineralization of the humus and soil wearing out of nutritive elements (nitrogen, phosphorus and potassium).

1.1. Humus degradation

The humus is one of the main indicators of soil fertility. This fundamental component determines, to a great extent, the physical, chemical, and biological properties of the soil. At the same time, it constitutes a source of nutritive elements for the plants. Being a multi-componential substance, the humus also represents an accumulator of conserved energy.

The humification represents a complex process of transforming the organic matter incorporated in soil [8]. The accumulation of humus in soil took place in a long period of time, from the first stages of solidification until the inclusion of the stiffened soils in the arable agricultural circuit. This period lasted for about 10–15 thousand years. Simultaneously with the increase of the contents of organic matter in soil, the accumulation of nitrogen and of other biophile elements occurred.

The chernozems, including the ones from the Republic of Moldova, were studied in details by the founder of genetic pedology, V. Dokuceaev [9]. After a century, research on the topics investigated by the great scholar has been done anew. Analyses of the contents and the state of humus in different subtypes of chernozems have been undertaken again. Generalizations are presented in multiple scientific works [7, 10, 11]. It was stated that in the course of 100 years (from 1881 up to 1981) the contents of humus in different subtypes of chernozems from various regions in Russia decreased by 27–53% (Table 1.1.1). The annual humus losses constituted 0.5–0.9 t/ha for this period. According to the data [7, 11] in the conditions of the Republic of Moldova, the humus losses from common chernozems constituted 30–40% or 50–70 t/ha for the same period. The speed of mineralization of the organic matter constituted 0.5–0.7 t/ha annually.

The experimental data obtained by A. Ursu [12] about the modification of the humus contents in the chernozems of the village Napadova, Floreshti district, which were studied by V. Dokuceaev in 1877 (Table 1.1.2), are of special interest. In the period of 83 years (1877–1960), the contents of humus decreased by 2.04% or by 35.7% of the initial ones. The speed of organic matter mineralization constituted annually 0.025%, while the humus losses constituted 0.89 t/ha. In the following 43 years (1960–2003), the contents of humus decreased only by 0.32%. In this period the speed of mineralization of the organic matter decreased considerably and constituted 0.007% annually. The losses of organic matter in soil constituted 0.27 t/ha. The agrochemical researches of the agricultural fields in the village Napadova carried out by the laboratory *Soil Agro-chemistry and Plant Nutrition* of "Nicolae Dimo" Institute in the year 2004 and 2007 demonstrated that the average contents of humus constitutes 3.30% and is identical with the data obtained later [12]. Since 2007 this field is included in the polygon network of "Nicolae Dimo" Institute in order to carry out the ecopedologic monitoring.

As consequence, in the course of 126 years (1877–2003), 2.36% of humus were mineralized or 41.3% of the initial reserves. The speed of dehumification of the organic matter constituted 0.018% annually. The annual humus losses constituted 0.67 t/ha.

The most significant humus losses in soil occur because of two processes: biological (dehumification) and soil erosion. In the Republic of Moldova, the surface of eroded soils constitutes about 40% of the arable lands. The annual losses of organic matter caused by erosion constitute 0.4 t/ha (Table 1.1.3).

Table 1.1.1. Modification of humus contents in different chernozem subtypes in the period of 100 years [10] (the layer of 0–30 cm).

Subtype of chernozem	Region	Humus contents and reserves				Humus losses		
		1881		1981		in 100 years (t/ha)	Annually (t/ha)	% from the initial contents
		%	t/ha	%	t/ha			
Typical	Tambov and Voronedz	10–13	300–390	7–10	210–300	90	0.9	23–30
	Kursk and Kharkov	7–10	221–315	4–7	142–248	69–79	0.7–0.9	21–36
Levigated	Stavropol Region	7–10	231–330	4–7	150–263	67–81	0.7–0.8	20–34
Common	Voronedz	7–10	221–315	4–7	150–263	52–71	0.5–0.7	17–32
	Republic of Moldova	4–7	126–221	2–4	75–150	51–71	0.5–0.7	32–40
Typical	Kuibishev	13–16	390–480	8–10	240–300	150–180	1.5–1.8	38–39
Common	Orenburg	9–11	270–330	6–8	180–240	90	0.9	27–33
Levigated	Ulianovsk	13–16	390–480	4–7	120–210	270	2.7	56–69

Table 1.1.2. Comparative data of the morphometric indicators and the humus contents [12].

Indicators		1877 (steppe)	1960, ploughed land		2003	
			Profiles		Ploughed land	Forest strip
			No. 42	No. 43		
1. Morphologic construction of the profile	A	0–61	0–43	0–44	0–50	0–50
	B	62–91	44–101	45–92	51–98	
	C	92	102	93	99	
	Effervescence	–	92	65	70	–
2. Humus contents	0–20	5.718	3.75	3.60	3.36	4.2
	30–40	–	3.65	3.30	3.15	3.0
	50–70	–	2.34	2.73	1.94	
	70–90	–	1.59	1.57	1.68	

Table 1.1.3. Evolution of humus balance in arable soils in the period 1971–2006, t/ha [5].

Year	Applied organic fertilizers (t/ha)	Humus balance	
		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
2001–2006	0.1	–0.7	–1.1

At the present stage of agricultural development, the humus balance in soil is negative and constitutes annually minus 1.1 t/ha [5]. The reduction of humus contents in soil, as a result of biological and erosion processes, leads to the worsening of its agro-physical, physico-chemical, chemical and biological properties. As a result, the production capacity of soils decreases, the obtained yields are low and of a bad quality.

It was found out that by the end of the 19th century the content of humus in Moldovan soils constituted 5–6%, and the reserves in the arable stratum were of 200 t/ha (Table 1.1.4).

With this amount of organic matter, the mineralization ability of the soil was high and contained 135 kg/ha of mineral nitrogen. In 50 years the content of organic matter constituted 4–5%. The amount of humus losses was about 25–30%, and the reserves of organic matter were reduced by 50 t/ha. The mineralization speed of the organic substance constituted about 1 t/ha annually. At the end of the

90s of the XX century the humus content decreased to 3.0–3.5%. According to the latest estimates [6, 13], the humus contents in Moldovan soils constituted an average of 3.1% in 1990.

Table 1.1.4. Modification of humus content in the soils of the Republic of Moldova.

Year	Humus (%)	Reserves in the layer of 0–30 cm (t/ha)		Mineral N, kg/ha
		Humus	Nitrogen	
1877	5.0–6.0	200	10	135
1950	4.0–5.0	150	8	115
1965	3.5–4.0	130	6	105
1990	3.0–3.5	110	5	80
2025	2.5–3.0	90	4	70

The estimates indicate that in the period till 2025, the humus content will reduce by 0.50% (35 years × 0.015%) or by18 t/ha and will constitute 2.5–3.0%, an average of 2.7%.

In these conditions, the primary actions to be undertaken for the improvement of the humic state of soils [6, 13] will include:

- Minimizing soil erosion through the implementation of a complex anti-erosion action system.
- Applying, to a great extent, the system for soil conservation which provides soil protection from erosion and reduces organic mater decomposition in soil.
- Utilization, production and application of organic fertilizers, optimal dozes of compost of about 9–10 t/ha in average in the crop rotation systems.
- Rational application of mineral fertilizers, 150–180 kg of NPK in average in crop rotation systems (Table 1.1.5).

Table 1.1.5. Modification of humus content depending on the active time and the system of soil fertilization (%) [6].

Type and sub-type of soil	Before the experience foundation	In 25–30 years		
		Unfertilized	$N_{60}P_{60}K_{60}$	$N_{120}P_{60}K_{60}$
Brown	2.5	2.4	3.0	2.5
Chernozems:				
Leache	4.0	3.2	3.6	3.8
Ordinary	3.0	2.7	2.8	3.0
Carbonated	3.8	3.1	3.5	3.2
Average	3.3	2.8	3.2	3.1

The implementation of the complex of measures in the Experimental Stations of “Nicolae Dimo” Institute led to the conservation and increase of soil fertility, including the organic matter [6].

1.2. Soil wearing off with nutritive elements

Any nutritive regime has its specific peculiarities. In the conditions of the Republic of Moldova that nutritive regime is considered optimal that ensures the obtaining of production determined by humidity. According to the estimates [5, 6], the multi-annual average precipitation quantity permits to obtain a yield of 4.2–4.5 tons of autumn wheat, 5.5 tons of corn for seeds, 2.5 tons of sunflower. In order to obtain these yields, a needed quantity of nutritive substances is necessary.

The chernozems of the Republic Moldova are characterized by a moderate content of humus (about 3.0%), a decreased content of mobile phosphorus, and an optimal quantity of changeable potassium. It was established [14] that in the course of the last 105 years the balance of biophile elements in Moldova’s soils was negative. The years 1980–1990, which was the period of intensive use of chemicals in agriculture, were an exception. In this period the balance of nutritive elements was positive. According to the data in the period of 105 years, 11.1 t/ha of NPK, including 3.4 N; 0.9 t P_2O_5; 6.8 t/ha K_2O were extracted and exported with the obtained harvest.

The chemical degradation led to the intensification of worsening the physical and biological properties of the soil and, as a result, the productivity of the agricultural lands decreased.

At present, phosphorus and nitrogen are the nutritive elements of prior minimum. The nitrogen issue in agriculture can be solved positively without harming the environment only by the creation of a neutral or positive balance of the humus in soil and of the closed nitrogen circuit in the chain – soil – agricultural farm – soil. The creation of the closed nitrogen circuit in the rural region would result in diminishing soil pollution, and especially of the surface waters, with nutrients, and first of all, with nitrates and the improvement of the ecological state.

In order to improve the mineral nutrition of the agricultural cultures with nitrogen, the following actions should be undertaken: the use of biological nitrogen in the quantity of 30–35 kg/ha by increasing the quota of vegetable cultures in crop rotation up to 20–25%; the production of organic fertilizers and their application in phyto-techniques in optimal dozes; the rational use of nitrogen fertilizers according to the needs of the agricultural cultures [5].

The efficiency of nitrogen fertilizers depends, to a great extent, on the quantity of the mobile phosphorus in soil. The natural fund of this element in Moldova’s soils is low and ensures the formation of 24–27 g/ha of autumn wheat. In the period of intensive use of chemicals (1966–1990), about 960 kg of phosphorus were incorporated in soil per hectare [14]. The systemic application of fertilizers in crop rotation fields radically improved the nutritive regime and plant nutrition with phosphorus. By the year 1990, the contents of mobile phosphorus in the agricultural fields was the following: 24.4% low, 33.6 moderate, and 42.4 high. The average doze of P_{55} achieved in the year 1990 was sufficient to form a multi-annual cycle of the optimal level of mobile phosphorus by 3–4 mg/100 g of soil. Since 1990 the quantity of phosphorus applied in agriculture radically decreased and in the last 5–6 years constituted 1 kg/ha.

In order to conserve the already formed level of mobile phosphorus in soil and to decrease the speed of degradation the following actions are to be undertaken: incorporation of P_2O in soil simultaneously with the sowing of cultures; the systematic application of fertilizers in recommended dozes in order to form optimal levels of mobile phosphorus in soil and maintaining them by compensating the export of P_2O_5 with the harvests. In the fields possessing an optimal or high level of mobile phosphorus in soil, it is necessary to apply recommended dozes of nitrogen fertilizers aiming at decreasing the speed of immobilization and observing the advanced technologies.

In order to obtain high yields, the agricultural crops extract considerable quantities of potassium from soil. Moldova's soils are rich in total and changeable potassium. It has been established experimentally that the quantity of potassium of 20 mg/100 g of soil is sufficient for obtaining high yields [13]. In the period of intensive use of chemicals a balanced equilibrium of potassium in soil was formed. At present the balance of this element is extremely negative. In spite of the fact that the soils are rich in potassium accessible to plants, in a period of over 150–200 years the reserves may be exhausted. Hence, it is necessary to compensate the potassium losses by applying fertilizers and first of all organic ones.

2. Conclusions

1. A lengthy utilization of soil in agriculture (after unfallowing) leads to the decrease of humus content in the soil. Losses of organic matter occur because of biological (dehumification) processes and soil erosion. In a period of 100–135 years the reserves of humus in Moldovan soils decreased by 40–47% because of mineralization.
2. In various periods of chernozems utilization in agriculture, the soil losses were different and constituted:

   0.035–0.025% of organic matter is mineralized annually in the first 5–30 years;

   in the following 30–100 years, the mineralization speed of organic matter is lower and constitutes 0.025–0.018% or 0.5–0.9 t/ha annually; soil losses are great and constitute 20–40% from the initial amount (before unfallowing);

   in a period longer than 100 years (from 100 to 300) humus losses constitute 40–47% out of the initial amount. Annually, 0.013–0.018% or 0.5–0.6 organic matter is mineralized.

3. It was stated that in a period of 105 years 3.4 t/ha N, 0.9 t P_2O_5 and 6.8 t/ha K_2O were extracted and exported with the harvests from the soils of Moldova.
4. The soil chemical degradation led to the intensification of physical and biological degradation and as result the production capacity of agricultural lands decreased by 35–40%.
5. In order to increase the soil fertility, the Complex Plan for the improvement of degraded soils and the increase of soil fertility was elaborated which determines the set of agrochemical, phytotechnical, and pedo-improvement measures. Its implementation guarantees the increase of yields by 40–45% and the environmental protection from degradation and pollution.

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